The Imperial Valley is the largest area, having about 75 percent of the total irrigated area which is served by California's Colorado River agricultural supply. Coachella Valley represents about 10 percent of the total irrigated area of the four valleys. These areas started irrigating the desert around the turn of the twentieth century. In 1987, both districts received a proportion of the 3.85 million acre-feet of California's Colorado River entitlement.

Most of the lands in both districts slope toward a previously dry lake bed now referred to as the Salton Sea. The Salton Sea was created in 1905 when the Colorado River flowed unimpeded into the Imperial Valley for over two years. Today it represents one of the 10 largest lakes in the United States (excluding the great lakes). Since the initial flooding of river water, the Salton Sea has been maintained by agricultural runoff from Imperial, Coachella, and Mexicali Valleys with additional inflow from rainfall, storm runoff and groundwater flows. Evaporation is the only method by which water is removed from the sea.

Imperial Valley contains relatively recent deposits of water-transported soil (SCS 1981). The area is composed of recent alluvial and lacustrine deposits of the Colorado River. Material was moved from several states and irregularly distributed due to the river variations and fluctuations of the old lake that once existed in part of the area. Imperial Valley soils are typically a cracking clay as opposed to the coarser soils found in the Coachella Valley. Cracking clays are characterized as soils with high initial intake rates which nearly seal once the cracks have been filled. Soils of the Coachella Valley are composed of recent alluvium deposits of the Whitewater River and other local streams. Coarser soils are capable of higher infiltration rates throughout an irrigation event.

The growing season is year-round with temperatures exceeding 100°F occurring more than 100 days in the year. The annual frost-free growing season is about 300 days. These regions supply the United States with a large component of fresh vegetables and fruits consumed in the winter months. Historical precipitation is less than 3 inches per year.

Water supplies from an artesian basin underlying the Coachella Valley were the source of irrigation water for the Coachella Valley from 1902 until 1949. CVWD was organized in 1918 and covers over 650,000 acres. CVWD supplies Colorado River water to about one-tenth of the total area, referred to as the "command area" in this report. Irrigation water in CVWD's command area is supplied both by surface water deliveries and groundwater supplies pumped by individual landowners. There is also land outside of CVWD's command area that is supplied entirely by groundwater. The irrigated acreage reported by CVWD includes all irrigated land both inside and outside the command area. All of the urban water demands are supplied by the groundwater including golf courses and the resort areas near Palm Springs.

The district was organized in response to groundwater supplies which were rapidly being depleted. In 1949, the 124-mile Coachella branch of the All American Canal was constructed allowing CVWD growers to reduce the groundwater depletion and increase the amount of irrigated acreage. CVWD began receiving Colorado River water in 1949.

CVWD has almost 2,000 delivery points and maintains a delivery system primarily of buried pipelines to deliver water to each 40-acre parcel within the command area. During summer months, CVWD uses a rotation schedule for irrigation delivery due to limited supply capacity. This has resulted in many of the growers in the CVWD constructing on-farm reservoirs to allow the growers additional flexibility in the irrigation of crops. Additionally, the majority of the acreage has access to groundwater from private wells.

CVWD experienced drainage problems prior to receiving surface waters from the All American Canal. After the surface water was introduced, a large portion of the area was affected by high water tables from a salty, perched water table. This shallow water table was (and is) being supplied by upslope irrigations that deep percolated to this unusable aquifer. CVWD installed open drains, buried pipe drains, and concrete-lined drains connecting a tile outlet to each 40-acre parcel. There is not a provision to remove surface runoff (tailwater)--only the subsurface flows. Over half of the irrigated acreage in the CVWD command area has the capability to remove subsurface flows. A large, unknown component of subsurface flows from the semiperched zone goes directly to the Salton Sea and is not monitored. The CVWD command area overlies a shallow aquitard that separates an upper and lower aquifer. Growers in the lower Coachella Valley pump groundwater from the lower aquifer zone. The upper, semiperched zone is supplied by overirrigation with some of this penetrating into the lower aquifer. Some of the subsurface flow is intercepted by the tile systems. The remainder of the perched water flow goes underground directly into the Salton Sea.

2.3 IMPORTANCE OF STUDY

Litigation starting in the mid-1970s was in response to rising waters in the Salton Sea creating flooding conditions on properties surrounding the Salton Sea. Property owners brought cases against CVWD and Imperial Irrigation District (IID) for compensation of flooded lands. After years of a common struggle to bring irrigation to the desert, the districts were on opposite sides of the courtroom debating the amount of liability in several lawsuits. The DWR published a report in 1981 stating the potential for 438,000 acre-feet of water savings in the Imperial Valley. In 1984, the USBR made a similar finding for the Imperial Valley and stated 350,000 acre-feet of water could be conserved. The State Water Resources Control Board (SWRCB) issued Decision 88-20 requiring IID to conserve 100,000 acre-feet by 1994. IID entered into an agreement with Metropolitan Water District (MWD) of Southern California to pay $98 million for capital improvement projects and annually transfer about 106,000 acre-feet of conserved water to MWD for 35 years. This landmark agreement will be fully implemented in 1995.

Various reports have been generated over the years by consultants, government agencies, and the district regarding irrigation efficiencies. Discussions regarding efficiency often do not clarify the efficiency definition or the boundaries of the area described (i.e., whether the efficiency is on-farm or district). Furthermore, completely different methodologies and assumptions are generally used, some of which appear to be inaccurate. This study was designed to review data presented in the previous court cases and determine the on-farm irrigation efficiency of CVWD. In order to prepare an accurate report, the following new information and data was generated as part of this study:

- Acreage in Coachella Valley within the CVWD command area based on independent (DWR) analysis

- Estimate of agricultural groundwater pumpage in CVWD

- Current crop coefficients (Kc) and annual ET used by researchers for various crops

- Long-term leaching requirement (LR)

2.4 STANDARD DEFINITIONS

These definitions are from current literature used for discussing irrigation efficiency. These reflect the current trends in describing the conditions of irrigation. These terms are specifically defined for evaluating on-farm irrigation efficiency.

Efficiency Terms

- Beneficial Water Uses - At the farm level, this includes transpiration needed for desired crop growth (majority), leaching for salinity control (not including nonuniformity), special practices such as packing the soil for harvest, weed germination, climate control, and some percentage of tailwater, which helps maintain a favorable salt balance.

- Nonbeneficial Uses - Weed transpiration, deep percolation in excess of leaching requirement, deep percolation due to nonuniformity of irrigation, evaporation from wet soil surfaces, evaporation from wet foliage, canal and pipe losses, and uncollected tailwater (minus some percentage which contributes to salt balance).

- On-Farm Irrigation Efficiency - Defined as the ratio of the irrigation water beneficially used to the irrigation water applied to the fields. Beneficial water use is defined above.

- Distribution Uniformity (DU) - Describes how evenly water is made available to crops in a field. DU is defined as the ratio of the depth of water received by the 25 percent of plants receiving the least amount of water, to the average depth of water received by all plants. Standard methods of determining DU are published in the Cal Poly (SLO) Irrigation Evaluation Manual (1992) and are used by the DWR Mobile Labs operating in Coachella Valley and throughout California. DU is typically low on coarse soils as compared to heavy soils regardless of irrigation system type.

Irrigation Terms

- Microirrigation - The frequent application of water in small quantities directly on or below the soil surface. Microirrigation is typically synonymous with drip irrigation, but also includes microspray systems. Microirrigation is well suited to the CVWD where coarse soils and permanent crops are grown.

- Row Irrigation - The application of water using furrows (3- to 6-foot centers) to irrigate. This method of irrigation can have high DUs if managed correctly on heavy soils.

- Flat Irrigation - The application of water using borders (50- to 200-foot centers) in which almost the entire soil surface is covered with water during irrigation. This method of irrigation can have high DUs if managed correctly, on heavy soils and with adequate laser leveling.

- Hand-Move Sprinklers - A portable sprinkler system that can be installed on a field consisting of aluminum mainlines and impact sprinklers on short risers. These are used for germination of salt-sensitive crops.

- Tailwater (TW) - Represents the component of delivered water to a farm which runs off the lower end of the field. Tailwater is required to achieve a uniform surface irrigation of an entire field. More tailwater is needed for row irrigation than for flat irrigation.

- Deep Percolation (DP) - Represents the component of delivered water that passes through the soil root zone.

- Tile Lines - Buried perforated pipelines installed in a field to remove a shallow water table from the root zone of a crop. Lines are typically 4 inches in diameter and spaced between 50 feet to 200 feet, depending on the soil type of the field.

Crop Water Use Terms

- Potential Evapotranspiration (ETo) - This is the value of the maximum water use of an unstressed grass reference crop. ETo is calculated on an hourly basis using weather data collected at each of the weather stations in DWR's CIMIS network. Hourly, daily, and annual ETo values are published by DWR for the CVWD. In 1987, the ETo of the Thermal CIMIS weather station was 73.1 inches.

- Kc - The Kc is the crop coefficient. This value represents the multiplier for estimating the crop ET where ETc = (Kc) x (ETo). Values for Kc are constantly being updated and revised as new information is generated on different crops and varieties. The Kc is different at each growth stage of the crops.

- Actual Crop Evapotranspiration (ETc) - The actual crop evapotranspiration may not be as great as the crop evapotranspiration which is calculated using ETo and Kc values if unintended stress occurs. In the CVWD, the coarser soils allow for unstressed crop ETc requirements to be applied. Therefore, it was assumed the potential crop ETc in the CVWD is equal to the actual crop consumptive use except for conditions (such as grapes) in which growers deliberately stress plants at certain times of the year for horticultural purposes.

- Leaching Requirement (LR) - In arid or semi-arid conditions, rainfall is less than what a crop will use during a growing season. Since crops remove relatively pure water from the soil, salts from the irrigation water are left behind. Some plants, such as lettuce, are sensitive to salts. Other crops, such as cotton, are salt tolerant. LR is the fraction of the infiltrated irrigation water at a point in the field which deep percolates and is necessary to maintain a desirable salt balance at that point. The LR fraction does <u>not</u> include water needed to overcome deep percolation problems caused by nonuniformity (i.e., by a DU of less than 100 percent). Some amount of deep percolation at a point (in excess of the required LR) due to nonuniformity may be reasonable, but none of it is beneficial.

- Leaching Fraction (LF) - The LF represents the actual fraction of water which deep percolates through the root zone and is considered to be beneficially used for salinity control. In this report, it does not include excess deep percolation caused by nonuniformity.

- Effective Precipitation (EP) - The amount of rainfall in a year that can actually be used by the crops.

Acronyms and Names Used by Public Agencies:

- CIMIS - California Irrigation Management Information System

- CVWD - Coachella Valley Water District

- CVRCD - Coachella Valley Resource Conservation District

- DWR - California Department of Water Resources

- EPA - Environmental Protection Agency

- ESA - Endangered Species Act

- Inlands Surface Waters Plan - New water quality objectives adopted in 1991 by the SWRCB placing numerical limits on specific constituents of surface waters including rivers, streams, and man-made agricultural drainage channels.

- IID - Imperial Irrigation District

- MWD - Metropolitan Water District of Southern California

- NOAA - National Oceanic Atmospheric Association

- SCS - Soil Conservation Service

- SWRCB - State Water Resources Control Board

- o USBR - United States Bureau of Reclamation
- o USGS - United States Geological Survey

2.5 WHY 1987 WAS SELECTED

The calendar year 1987 was determined to be a fairly representative climate year for data analysis. Since a detailed analysis was required, only one year's data was evaluated. The most significant unknown value was the irrigated crop acreage in the CVWD command area. An in-depth agricultural land use study by the DWR was last done in 1987 for CVWD. The USGS report on groundwater conditions had published data through 1986. Complete 1987 power records for Coachella Valley agricultural pumping were available from IID (which has supplied power to the Coachella Valley since 1943). Aerial photography was also available from the same time frame. Selection of 1987 also allowed for optimal use of court data that was available.

Section 3

ON-FARM IRRIGATION EFFICIENCY

The basic idea of on-farm irrigation efficiency is fairly well understood. However, the methods used to calculate the variables in the equation vary widely. In its simplest form, the equation is as follows:

$$\text{On-Farm Irrigation Efficiency} = \frac{\text{Irrigation Water Beneficially Used} \times 100}{\text{Irrigation Water Applied}} \qquad \text{Eq. (3-1)}$$

One of the major problems in educating the general public about agricultural water use is simply the wide variety of irrigation efficiency definitions. Equation 3-1, as stated above, is accepted by the California Department of Water Resources (DWR) Office of Water Conservation for use in the DWR water management programs. This equation is also accepted by definitions of the American Society of Civil Engineers (ASCE) Irrigation and Drainage Division.

Any comparison of on-farm irrigation efficiency (IE) calculations must carefully consider how "beneficial use" and "applied water" were both defined and computed. Discrepancies in estimates of IE arise because of several factors. Some of these differences are minor but others can significantly alter results on an analysis of a large area. It is the intention of this report to evaluate the current numbers and assumptions used by irrigation professionals and determine the most reasonable approach. The following are some of the factors that cause differences between reports:

- Sources of water other than canal
- Incorrect acreage
- Actual crop ETs are less than potential crop ETs
- Some of the ET is due to other sources of water
- Potential crop ETs are not always known for a region
- Actual leaching fraction (LF) can be less than the LR
- Correct LR is debatable
- Confusion between efficiency terms (distribution uniformity, on-farm irrigation efficiency, district irrigation efficiency, seasonal irrigation efficiency, single event irrigation efficiency, motor/pump efficiency, water use efficiency)
- Errors when describing water use (reasonable vs. beneficial, actual vs. potential, theoretical vs. measured)

"Beneficially used irrigation water" has been defined earlier. The primary beneficial use components in 1987 for CVWD were (1) crop transpiration and (2) leaching for salt control. This report emphasizes the correct estimation of both parameters and utilized information from a variety of reputable sources.

Various publications have provided a range of values for ETc of major crops in CVWD. Various references were analyzed for the accuracy and completeness of the data collection and estimation procedures. For some crops, this report compares reported ETc values with calculations using transferrable techniques (e.g., Kc x ETo) to determine the most reasonable and unbiased ETc values. Of particular interest were the values for citrus in CVWD. Discrepancies between reported values of crop transpiration are discussed, and justifications are given for the values used in this report.

On the salt control aspect, a detailed discussion of LR computations is provided in the appendix of this report. Of particular note are (1) the correct definition of LR does not include deep percolation caused by nonuniformity, and (2) LR computations for nonpermanent crops must plan for the most salt-sensitive crop which will be grown in a crop rotation on a field rather than for the "average salt tolerance" of the rotated crops.

For the irrigation water applied, the reported on-farm water deliveries were used as the basis. CVWD measures and charges growers for the amount of water delivered to each field. The growers have the opportunity to scrutinize the billings for accuracy.

Taking into account the definition of beneficial use and the area where water is applied, the equation is restated as follows:

$$\text{Theoretical Irrigation Efficiency} = \frac{\text{Portion of Actual ET of Crops Supplied by Irrigation Water}}{\text{(Irrigation Water Dedicated to the Area)*(1-LR)}} \qquad \text{Eq. (3-2)}$$

The geology of CVWD includes very sandy soil, which allows for considerable deep percolation of on-farm irrigation water. This deep percolation cannot be directly measured. Only part of this deep percolation water enters the Salton Sea through drain tiles; the majority of the remainder flows underground directly into the Salton Sea.

Therefore, CVWD must estimate the on-farm irrigation efficiency without ever having a means of verifying the accuracy of the computation. Specifically, the only way one can truly verify the accuracy of the IE computation is to be able to accurately measure all the deep percolation. Since this is impossible with the CVWD geology (and in most other areas of California as well), estimates of the on-farm irrigation efficiency are made with the following equation:

$$\text{On-Farm Irrigation Efficiency} = \frac{\text{Crop ETc - Effective Rain}}{\text{(Delivered Water)*(1-LF)}} \qquad \text{Eq. (3-3)}$$

This report shows that some of the numerical values which have been used in the historical CVWD computations are incorrect. Specifically, four errors have typically occurred with the computations:

- o The per-acre ETc of citrus in efficiency reports have generally been overestimated.
- o The cropped acreage which has been used in the computations has included all irrigated areas in CVWD rather than just the irrigated area served directly by the Coachella Canal (command area).
- o The "delivered water" must include all irrigation water delivered through on-farm irrigation systems (both from the Coachella Canals and from wells); well water has been underestimated.
- o The LF has included nonbeneficial components of deep percolation due to nonuniformity.

Section 4

ON-FARM IRRIGATION EFFICIENCY AND DISTRIBUTION UNIFORMITY

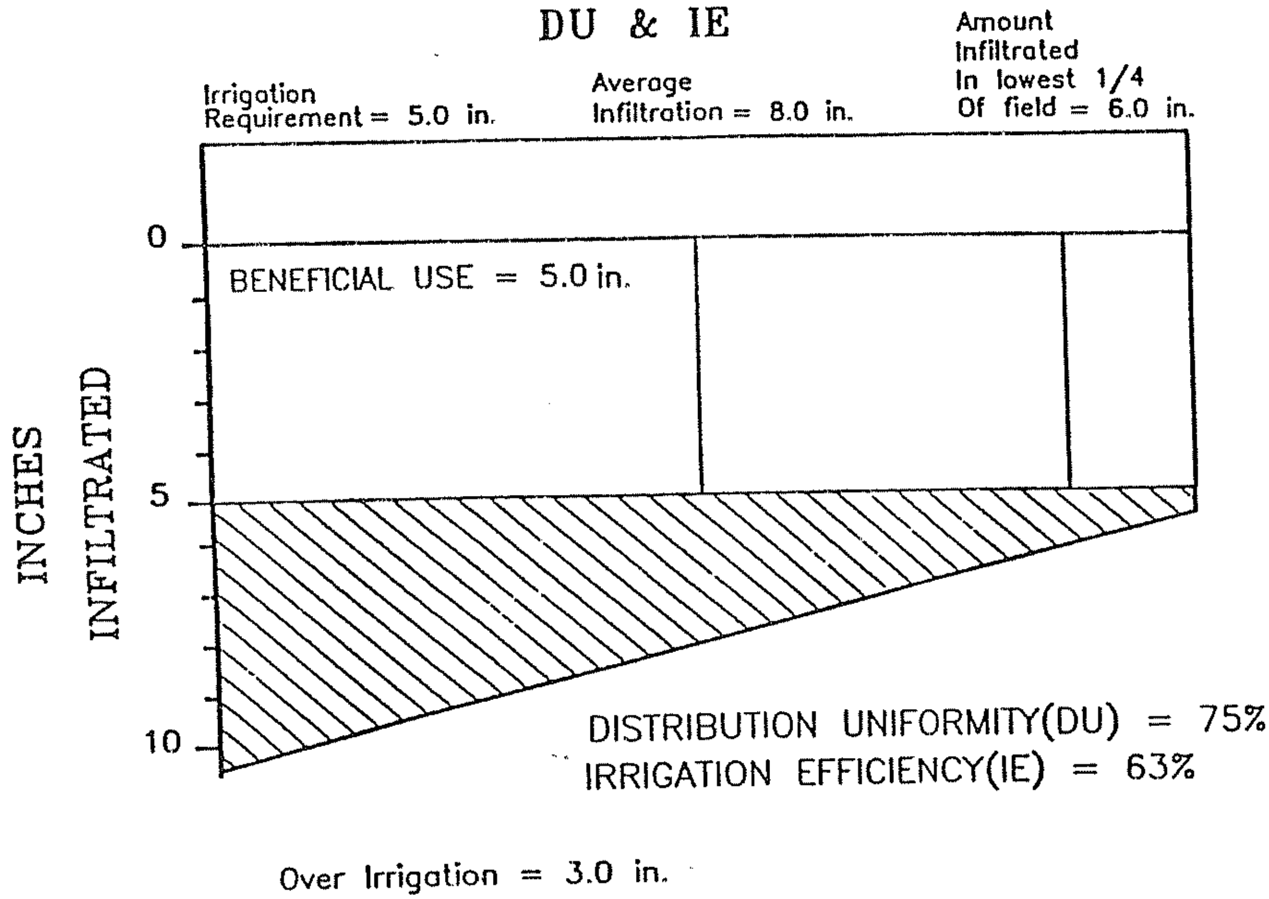
The Coachella Valley Resource Conservation District (CVRCD), assisted by the Soil Conservation Service, began performing irrigation system evaluations in the Coachella Valley in 1985. The main goal of the mobile lab is the measurement of distribution uniformity (DU) of the Coachella Valley's irrigation systems. The mobile lab does not typically perform measurements of the on-farm irrigation efficiency due to the complex and dynamic nature of determining the variables of a single event irrigation. The CVRCD has published some of the findings with respect to the operation of microirrigation systems in several reports. The most comprehensive report was released in 1991 titled "A Six Year Summary Analyzing Micro Irrigation Performance on Coachella Valley Farms." This section summarizes the findings of the CVRCD report and also includes discussions of other regions.

4.1 DISTRIBUTION UNIFORMITY

The distribution uniformity describes the evenness of water application. The field evaluation of distribution uniformity measures the ability of a system to deliver the same amount of water to each plant. When water is applied to a field, the water penetrates to different depths, depending on many factors. This can be shown two-dimensionally by plotting some finite amount of measured grid points from a field.

Rearranging the data from the largest to smallest amount of infiltrated water, the DU can be solved graphically as in Figure 4-1. The DU is the ratio of the depth of water infiltrated to the region receiving the lowest 25 percent of the infiltrated water to the average depth of the infiltrated water. Figure 4-1 was derived from CVWD Exhibit 1065 for the Torres-Martinez case for Coachella Valley. Assuming a grower wishes to optimize the application of irrigation water, the grower must take into account the DU when calculating the amount of water to apply. This means that if the calculated water requirement was 5 inches and the DU is 75 percent, the grower should apply a total of 6.7 inches (5 inches/75 percent) to ensure that only the lower one-eighth of the field is underirrigated. If less than 6.7 inches of water is applied, then more of the field would be underirrigated. If more than 6.7 inches of water is applied, overirrigation would occur.

The only data that is published for the measure of DU in the Coachella Valley is for microirrigation systems. The results of 177 microirrigation irrigation evaluations performed between 1984 and 1990 resulted in an average DU of 76% (CVRCD, 1991). The range of measured values ranged from a low of 18% to a high of 97 percent. Only a portion (about 40%) of the Coachella Valley uses microirrigation. The majority of the Coachella Valley uses other irrigation systems that have considerable lower potentials for high DUs due to the sandy soils. With row irrigation in coarse sandy soils, it is difficult to achieve high DU values unless many structural and nonstructural improvements are made to the system. For example, a tailwater



Source: CVWD Exhibit 1065 Torres-Martinez Case

Assumptions:
- Sandy Soil
- Zero Runoff
- Beneficial Use (Irrigation Requirement) Includes Both Crop Transpiration and Leaching for Salt Control

recovery system and shorter field lengths would be necessary to obtain high surface irrigation DUs in the Coachella Valley. Therefore, the average DU of irrigations of CVWD must be less than 76 percent. Furthermore, the inherent inefficiency of surface irrigation systems without tailwater recovery systems (as is the case in CVWD) on sandy soils means the IE must also be much lower than 76 percent.

4.2 RESULTS FROM OTHER REGIONS

Data reported by the Westlands Water District indicate high DUs are obtainable on row-irrigated fields with heavy soils. Westlands also found that by using Equation 3-3 (Section 3) the irrigation efficiency was overstated because of poor irrigation scheduling and nonuniformity (Westlands Water District, 1987). The average field distribution uniformity reported for 335 evaluations was 72 percent. This data included measurements on row-irrigated fields, drip irrigation, sprinkler irrigation, and combinations of systems.

Data from Monterey County Water Resources Agency indicate measured DUs of 68 percent for 72 irrigation evaluations performed by a mobile laboratory. Due to the high value of most crops grown in the Salinas Valley and based on field observations, all fields were assumed to be wetted sufficiently. The distribution uniformity for Salinas Valley is therefore the upper limit of the on-farm irrigation efficiency.

4.3 IRRIGATION EFFICIENCY

To state that the irrigation efficiency is greater than the DU would require that a large portion of the fields be underirrigated. Based on visual observations of CVWD and discussions with local irrigation specialists, this does not appear to have occurred in 1987. In other words, the on-farm irrigation efficiency must be less than the measured DU for the district. In the example shown from CVWD data on Figure 4-1, the on-farm irrigation efficiency for this field event was 63 percent.

Westlands Water District reported on-farm irrigation efficiency of 64 percent (Westlands Water District, 1987). For Salinas Valley, the on-farm irrigation efficiency is less than 68 percent (based on the available data).

In summary, the distribution uniformity of the CVWD command area is less than 76 percent. Due to the conditions in the Coachella Valley, the irrigation efficiency must be less than the DU.

Section 5

WATER AVAILABILITY IN STUDY AREA

5.1 SURFACE WATER DELIVERY

Data reported in the Torres-Martinez court case was used to evaluate the total volume of water delivered by the USBR to CVWD. The CVWD command area received 325,000 acre-feet in 1987 below Check 6A as the reference point. Water accounted for and charged to the agricultural water users was 279,000 acre-feet. The difference of 46,000 acre-feet (14%) is accounted for from operational discharges, seepage from pipelines, and seepage/evaporation from canals and storage reservoir.

5.2 IRRIGATED ACREAGE

Reported irrigated acreage varies considerably depending on the source of the information. This is due to several factors:

- o Time of year for determination.
- o Groupings of the crops. (Specific guidelines are different for DWR or the county agricultural commissioner's offices.)
- o Harvested vs. planted acreages. (Some crops are planted in the fall and harvested in the next spring.)
- o Database source (internal vs. external records).

CVWD reported acreage was not used because the data included lands outside the command area.

Included in Appendix B is a detailed breakdown of the data collected from the December 1990 report by DWR entitled "South Lahontan and Northern Colorado Desert Land Use Study, 1987" by crop and USGS quadrangle reference. Additional information used in the generation of the DWR report was obtained from the DWR Southern District office in Glendale, California. Additional data included the computer "tab" data files as well as the published report material. DWR drafted results of its aerial and ground truthing analysis onto United States Geological Survey (USGS) 7-1/2 minute quadrangle sheets for the 1987 crop year. Each quadrangle with cropped acreage was copied and compared to the service area boundary of the CVWD as reported on CVWD Drawing No. 48A dated March 1986. Each quadrangle was then summarized by crop for the irrigated acreage within the command area and outside the command area.

Aerial photography used in the DWR analysis was obtained from the USGS. The aerial photographs were from 1985. Adjustments were made to the data by DWR to reflect the growing conditions in 1987. Acreage within the CVWD service area or "command area" was calculated separately from the acreage outside of the service area boundaries for this report. Separation of the acreage was not done in the summary information published by the DWR report or by CVWD. Table 5-1 is a summary of the investigation into the irrigated acreages both within and outside of the CVWD command area. The summary includes a calculation of the double-cropped acreage.

5.3 GROUNDWATER PUMPING

5.3.1 Groundwater Usage in CVWD

Groundwater pumping in the CVWD supported irrigated agriculture until 1949 and is used today to provide irrigation water to areas both inside and outside of the CVWD command area. Additionally, the groundwater use is increasing due to urban demands since all urban water in Coachella Valley is supplied by groundwater.

Figure 5-1 shows approximate soil profiles of both the Imperial and Coachella Valleys. This figure illustrates the major difference between the two valleys. In Imperial Valley, there is a clay layer on the surface that corresponds to heavy soil type that has low permeability and is difficult to infiltrate water and also drain. In the Coachella Valley, surface soils are typically light soils impacted by the presence of the shallow water table.

CVWD previously reported 34,400 AF of agricultural groundwater pumping in 1987 (Bookman-Edmonston, 1989). However, the flows on agricultural pumps are not metered; therefore, there have been no direct measurements. Instead, there have been various modeling studies on the groundwater basin as a whole using various assumptions. No study was found that had good data for agricultural pumping volumes for the command area.

5.3.2 Notes from Coachella Valley Groundwater Reports

DWR Bulletin No. 108 groundwater investigation was done in response to rapid expansion of both irrigated agricultural and urban lands within the Coachella Valley. The investigation was requested by CVWD in 1960. In general, the study was designed to analyze the groundwater in Coachella Valley for planning purposes. Shallow groundwater conditions were adversely impacted with the introduction of the Colorado River water supplies in 1949 especially in the region south of Indio.

The DWR study delineated four subbasins and four areas of the Coachella Valley Groundwater Basin. Of primary concern to the agricultural areas of the lower Coachella Valley is the Indio Subbasin. The Indio Subbasin is divided into five subareas. The Palm Springs subarea is the forebay or main area of recharge to the Indio Subbasin. The Thermal subarea is the pressure area within the subbasin. The Palm Springs subarea is where water is applied for the DWR/MWD/CVWD groundwater management program. The Thermal subarea is primarily where agriculture is located in the lower Coachella Valley. Within the Thermal subarea, there is

TABLE 5-1

CVWD - 1987 CROP ACREAGE SUMMARY

Crop (1)	Coachella Valley Irrigated Ag. Acres (2)	Gross Irrig. Ag. Acreage Outside of CVWD Supply (3)	Gross CVWD Command Acreage Irrigated (4)	Net (95%) Acreage Outside of CVWD Supply (5)	Net (95%) CVWD Command Acreage Irrigated (6)	Net (95%) Acreage Outside of CVWD Supply w/Double Crop (7)	Net (95%) CVWD Command Acreage Irrigated w/Double Crop (8)
Alfalfa	2,616	0	2,616	0	2,485	0	2,485
Broccoli	1,427	0	1,427	0	1,356	0	2,711
Carrots	1,509	82	1,427	78	1,356	156	2,711
Dates	5,925	609	5,316	579	5,050	579	5,050
Grapefruit	8,013	1,959	6,054	1,861	5,751	1,861	5,751
Grapes	20,077	6,514	13,563	6,188	12,885	6,188	12,885
Lemons	2,555	1,085	1,470	1,031	1,397	1,031	1,397
Lettuce	2,171	231	1,940	219	1,843	439	3,686
Mixed Pasture	1,570	149	1,411	151	1,340	151	1,340
Oranges	3,412	413	2,999	392	2,849	392	2,849
Misc. Truck	4,355	516	3,839	490	3,647	980	7,294
Misc. Field	1,488	535	953	508	905	1,017	1,811
Misc. Perm.	1,868	378	1,490	359	1,416	359	1,416
Ag. Ponds	1,040	1,040	0	988	0	988	0
Total	58,026	13,521	44,505	12,845	42,280	14,141	51,386

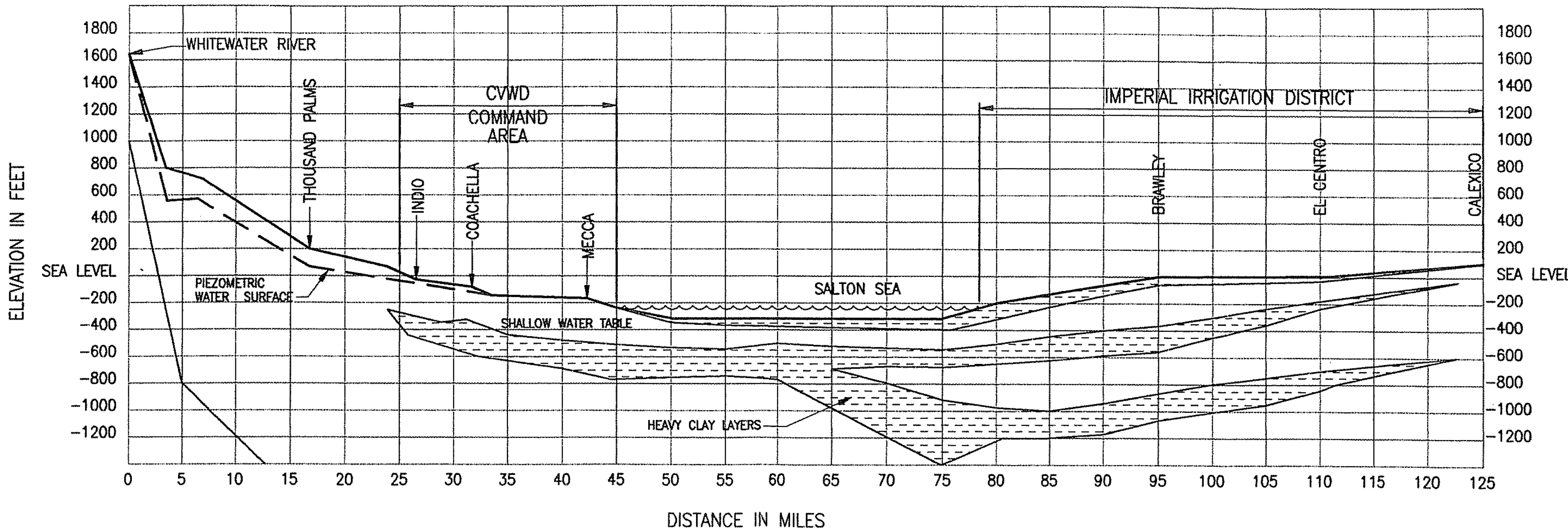
See next page for column descriptions.

TABLE 5-1 (continued)

Column Descriptions

1. Crop description.
2. Source: South Lahonton and Northern Colorado Desert Land Use Survey, DWR, 1990.
3. Determined by plotting CVWD boundary of command area on USGS quad sheets provided by DWR, 1990 report (Appendix C).
4. Determined same as Column 3.
5. Column 3 times 0.95 to account for a 5% acreage reduction due to farm roads and farmsteads.
6. Column 4 times 0.95.
7. Column 5 plus crops that were double cropped (carrots, lettuce, miscellaneous truck, and miscellaneous field).
8. Column 6 plus crops that were double cropped (broccoli, carrots, lettuce, miscellaneous truck, and miscellaneous field).

Refer to Appendix C for a detailed breakdown of the cropped acreage.



SOURCE:
CVWD EXHIBIT 1041, TORRES-MARTINEZ CASE AND PRELIMINARY FINDINGS OF IMPERIAL COUNTY GROUNDWATER INVESTIGATIONS

IMPERIAL IRRIGATION DISTRICT/COACHELLA VALLEY WATER DISTRICT

GROUNDWATER BASIN PROFILE

3-4-93

BOYLE ENGINEERING CORPORATION

FIGURE 5-1

a lower aquifer below the aquitard shown on Figure 5-1 where the agricultural pumping for the CVWD command area is done. Above the aquitard is a semiperched groundwater zone of unusable water. The semiperched groundwater is removed by on-farm tile systems, leakage to the lower zone on the fringes of the CVWD command area, and an unknown component of subsurface flow to the Salton Sea. There is not adequate data available to determine the amount of subsurface flow to the Salton Sea.

The 1964 DWR study indicated that annual agricultural groundwater extractions were approximated at 115,000 acre-feet. Since that time, additional agricultural acreage has been added, especially outside the CVWD command area. This new acreage was served entirely by groundwater supplies. Also, beginning in the 1970s, growers began using microirrigation systems on permanent crops. To increase the flexibility of using these systems, growers installed wells to supply these new systems.

The pumped groundwater comes from the following sources:

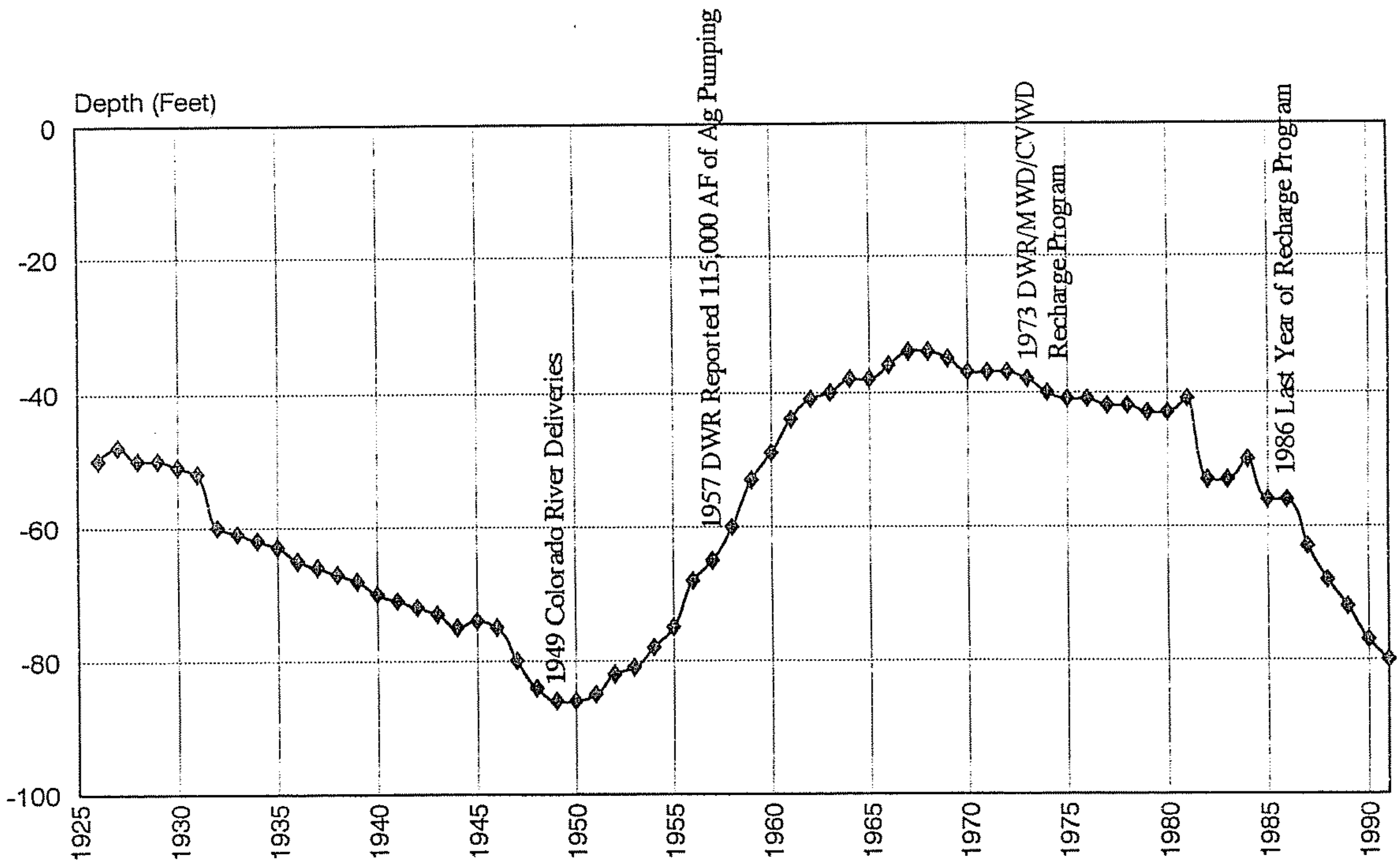
- Upper basin recharge from the Palm Springs subarea.
- Natural inflow from precipitation.
- Infiltration from canal seepage and irrigation. This occurs from leakage through the aquitard and along the fringes of the clay layers.
- Removal of groundwater storage.

USGS Report 91-4142 indicated that flows from the upper Coachella Valley recharge area to the lower Coachella Valley pressure area was occurring. Without additional modeling of the lower Coachella Valley, the USGS study concluded that it was not possible to assess the quantity of subsurface flows. Previous models and analysis have assumed a constant head boundary between the upper and lower Coachella Valley and the USGS study concluded that this assumption was not valid. In other words, the lower Coachella Valley is affected by the recharge efforts in the upper Coachella Valley.

Exhibit 1044 of the Torres-Martinez case included historic groundwater elevations from wells on the east and west sides of the lower Coachella Valley and are included in Appendix D. In general, the data reflect the trends shown on Figure 5-2. This data was from Exhibit 1044 of the Torres-Martinez case. Figure 5-2 shows that groundwater elevations were dropping until 1949, when deliveries from the Colorado River were initiated. Groundwater levels rose in response to leakage of groundwater from the semiperched zone of the Thermal subarea. Groundwater levels were rising in 1957 when 115,000 acre-feet of agricultural water was extracted (DWR Bulletin 108). Groundwater levels rose and were maintained into the 1980s. After the DWR/MWD/CVWD recharge program was discontinued in 1986, groundwater elevations have begun to drop off rapidly, indicating significant groundwater pumping.

These previous reports did not perform a thorough analysis of the agricultural groundwater pumping in the CVWD command area. In order to obtain a more precise value for the volume of groundwater pumped by growers within the CVWD command area, actual power usage for agricultural pumping (PA rate) was utilized in this report.

Groundwater Elevations Near Valerie
Average Annual Depth from Ground Surface



Reference: Coachella Valley Water District - Well 07S08E34G01S

5.3.3 CVWD Agricultural Groundwater Pumping Calculations

The approach used to determine the amount of groundwater pumping in the CVWD command area is graphically shown on Figure 5-3. The total pie represents the total energy use in Coachella Valley by agricultural users for pumping water. There are two main components of the pie: groundwater lifted to the surface and water that is boosted for microirrigation.

Groundwater lifted to the surface is applied to lands both inside and outside the command area. For the on-farm irrigation efficiency of the CVWD command area, the critical value to be solved is the energy required to lift groundwater within the command area (Section E on Figure 5-3). From this value, the volume of groundwater pumped within the CVWD command area can be calculated.

To determine the total pumping within the CVWD command area, the following equation was used:

Energy (KWH) used to lift water to ground surface (E) = Eq. (5-1)

Total KWH for Agricultural Pumping in Coachella Valley (metered)

- KWH used to lift water outside of CVWD command area (D)

- KWH used for microirrigation booster pumps (A, B, and C)

The volume of groundwater pumped to the surface in the CVWD command area can then be computed from the energy usage. The following calculation steps were used.

Step 1: Investigate total agricultural pumping energy use in Coachella Valley.

Step 2: Determine the volume of water applied to outside of the CVWD command area.

Step 3: Calculate the energy required for lifting water outside of the CVWD command area (D).

Step 4: Determine the volume of water boosted for microirrigation.

Step 5: Calculate the energy required for microirrigation booster pressure (A, B, and C).

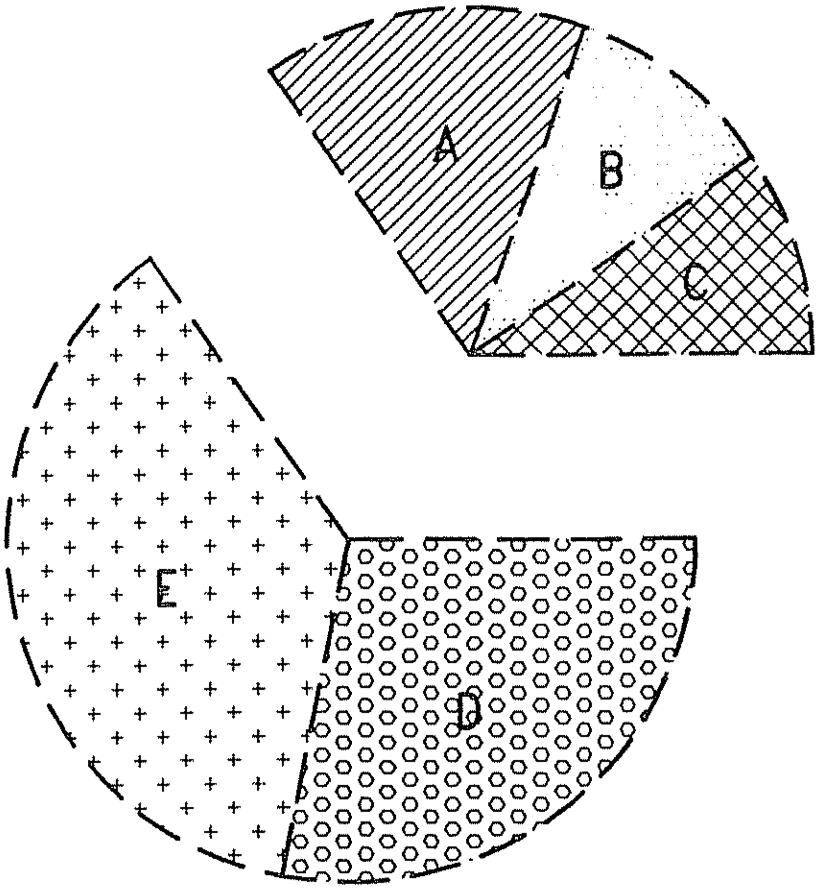
Step 6: Determine the energy used for lifting agricultural groundwater to the surface in all of CVWD (D and E).

Step 7: Determine the energy used for lifting agricultural groundwater to the surface in the CVWD command area (E).

Step 8: Solve for the agricultural groundwater (AF) pumped in the command area.

The following should be noted regarding the calculations for total water pumped by the region within the CVWD command area:

TOTAL PA ENERGY USE IN COACHELLA VALLEY (73 MKWH)



MICROIRRIGATION BOOSTER PRESSURE

A – BOOSTER PRESSURE NEEDED FOR MICROIRRIGATION SUPPLIED BY CANAL WATER, INSIDE COMMAND AREA.

B – BOOSTER PRESSURE FOR WELL WATER, OUTSIDE COMMAND AREA.

C – BOOSTER PRESSURE FOR WELL WATER, INSIDE COMMAND AREA.

LIFT FROM AQUIFER

D – LIFT FROM AQUIFER TO SURFACE, OUTSIDE COMMAND AREA.

E – LIFT FROM AQUIFER TO SURFACE, INSIDE COMMAND AREA.

FIGURE 5--3

- o The IID power department provides an agriculture pumping (PA) electrical rate for the farmers in the Coachella Valley. This was not supposed to include agricultural power used for wind machines, packing houses, residences, domestic wells, etc.

- o Basically, the agricultural pumping is used for one of two purposes:

  - Lifting water to the ground surface.
  - Providing sufficient pressure to match drip system requirements.

- o There is widespread use of diesel booster pumps in the area for sprinklers. Therefore, there was no need to estimate electrical booster usage for sprinklers.

- o Golf courses, as well as all urban water uses and abandoned lands were removed from the survey data base.

- o Efficiency of pumps in wells (impeller and motor) was assumed to be 65 percent based on discussions with local well specialists.

- o Efficiency of booster pumps was assumed to be 68 percent.

- o Irrigation efficiency for determining the amount of applied water for the region outside of the CVWD command area was assumed at 65 percent, which is higher than within the command area because the primary irrigation method in the outside region is microirrigation. Within the command area, the predominant irrigation methods are row and flat irrigation on sandy soils. The long-term leaching requirement was estimated to be 21 percent. It was assumed that the LF = LR.

The procedure used in this report was to first estimate the amount of groundwater pumped in the total area of the Coachella Valley, and then to compute the actual groundwater used only in the command area. The most complete metered information available is the total energy use (KWH) for agricultural pumping in the Coachella Valley.

<u>Step 1: Total Energy Use in Coachella Valley</u>: The IID power records indicate that from 1986-1991 the following energy was consumed by agricultural pumping (PA) in the <u>entire</u> Coachella Valley. Because the total KWH is similar for these years, it was concluded that 1987 was a typical year.

	Total PA Energy Consumed (KWH)
1986	73,971,473
1987	**73,059,851**
1988	72,936,102
1989	75,285,272
1990	76,370,483
1991	74,023,495

Step 2: Gross Water Applied to Outside CVWD Command Area: Equation 5-2 was used to estimate the gross water applied outside the command area.

$$\text{Gross pumped water} = \frac{\text{Area ETc - Effective Rainfall}}{\text{On-Farm Irrigation Efficiency}/100 \times (1\text{-LR})} \qquad \text{Eq. (5-2)}$$

The components of this equation are computed as follows:

o Area ETc. The acreage for the area outside the CVWD command area is found in Table 5-1 (column 7). The ETc data for specific crops is from Section 6 of this report. The area ETc is computed in Table 5-2.

Area ETc = 51,063 AF

o Effective Rainfall. The effective precipitation was assigned to be 30% of the total rainfall during 1987. The total rainfall was 4.26 inches in CVWD, resulting in an effective rainfall of 1.3 inches. The net acreage outside of the CVWD command area (not including double cropping) was 12,845 acres (Table 5-1, column 5).

$$\text{Effective rainfall} = \frac{1.3" \times 12{,}845 \text{ acres}}{12"/\text{ft}} = 1{,}392 \text{ AF}$$

o The assumed on-farm irrigation efficiency (IE) is 65 percent. Although not technically correct, an IE and LR are assigned to the ponds to account for seepage. The use of the higher IE number of 65 percent has the net effect of increasing the final estimate of on-farm irrigation efficiency within the command area.

Irrigation Efficiency = 65%

o The calculation of a long-term LR is discussed later in Section 6.3 of this report.

LR = 21% = 0.21

TABLE 5-2

SUMMARY OF WATER APPLIED OUTSIDE CVWD COMMAND AREA

Crops	Annual ETc (IN)	Total Acreage (AC)	Annual Crop ETc (AF)
Alfalfa	70.1	0	0
Broccoli	14.3	0	0
Carrots	21.0	156	273
Dates	73.1	579	3,524
Grapefruit	45.0	1,861	6,979
Grapes	39.9	6,188	20,576
Lemons	45.0	1,031	3,865
Lettuce	15.5	439	567
Mixed pasture	73.1	151	920
Oranges	45.0	392	1,471
Ponds - duck/fish	87.7	988	7,222
Miscellaneous truck	22.3	980	1,822
Miscellaneous field	32.1	1,017	2,719
Miscellaneous permanent	37.6	359	1,125
Total		14,141	51,063

In summary, the estimated applied irrigation water <u>outside the command area</u> is:

$$\text{Gross applied} = \frac{51{,}063\ \text{AF} - 1{,}392\ \text{AF}}{0.65 \times (1-0.21)} = \mathbf{96{,}730\ AF}$$

<u>Step 3: Energy Required for Lifting Water Outside of CVWD Command Area (Outside Lift KWH):</u> Since the area outside of the CVWD command area is supplied entirely with groundwater, an estimate was made of the energy consumption to lift the quantity of water required to satisfy the crop water use of this area (Section D on Figure 5-3). The following energy calculation was used to determine the amount of energy required.

$$\text{Energy KWH} = \frac{\text{AF Pumped} \times \text{TDH (FT)} \times 1.023}{\text{Pumping Plant Operating Efficiency}/100} \qquad \text{Eq. (5-3)}$$

The total volume pumped was computed to be <u>96,730</u> acre-feet (from Step 2). The total dynamic head (TDH) was estimated using the following variables: static lift, drawdown, discharge pressure, and minor losses. The static lift (depth to groundwater) was evaluated from various reports. The USGS report 91-4142 had the most extensive data but only was reported from 1979 to 1986 (Appendix E). Court records from the Torres-Martinez Case were also used. The groundwater levels vary depending on numerous variables but generally averaged about 95 feet in 1986 based on the USGS report for the entire Coachella Valley. The depth to groundwater of <u>100</u> feet was used to account for the lower water table from 1986 to 1987. A separate analysis was done for the wells on the fringe of the CVWD command area where the depth to groundwater averaged 115 feet in 1986. A depth to groundwater for the area outside of the CVWD command area of <u>120</u> feet was used to account for the lower elevations in 1987. Drawdown for the majority of the agricultural areas was estimated by local well specialists at 10 to 20 feet. According to USGS, some of the groundwater data may already include drawdown. However, a conservative estimated drawdown for the outside area was 20 feet. Since this calculation is only for the energy to lift the water to the ground surface, an estimated discharge pressure of 10 feet was used. Minor losses for the pumping unit were assumed to be 10 feet. (See Appendix F for calculation.) TDH for the area outside of the CVWD command area was <u>160</u> feet (120+20+10+10).

Static Lift (120')
\+ Drawdown (20')
\+ Minor Losses (10')
<u>+ Discharge Pressure (10')</u>
= TDH (outside CVWD command area) = <u>160 feet</u>

The pumping plant efficiency was assumed to be 65 percent. Based on discussions with local well specialists, if the pumping plant efficiency drops below 65 percent, growers typically will modify the pump to improve the pumping plant efficiency. Therefore, the energy required to lift groundwater to the surface in the area outside the CVWD command area was as follows:

$$\text{Outside Lift KWH} = \frac{\underline{96{,}730 \text{ AF} \times 160 \text{ FT} \times 1.023}}{65\%/100} = \mathbf{24{,}358{,}187 \text{ KWH}}$$

(Note: Values were not rounded)

Step 4: Volume of Water Boosted for Microirrigation in the Entire Coachella Valley: The volume of water which was boosted to pressurize the drip irrigation systems is shown on Table 5-3. The gross applied water to the entire Coachella Valley for microirrigation including surface water and groundwater was estimated to be **169,369 acre-feet** (from Table 5-3). Applying an irrigation efficiency and leaching requirement to the entire Coachella Valley area that pressurizes water for microirrigation was done to estimate the total water applied. This irrigation efficiency value was estimated to be lower than the measured distribution uniformity because there appears to be no evidence of intentional underirrigation on the drip systems within CVWD.

Step 5: Energy Required for Microirrigation Booster Pressure: The energy required to pressurize the water used for microirrigation was calculated by determining the discharge pressure microirrigation systems require and substituting this value for TDH in Equation 5-3. Also, the pumping plant operating efficiency of the booster pump was used (slightly higher for horizontal centrifugal booster pumps). The estimated energy required for microirrigation pumping taking booster pressure and pumping plant operating efficiency into account was estimated with the following equation:

$$\text{Booster Energy KWH} = \frac{\text{AF Pumped} \times \text{Discharge Pressure (FT)} \times 1.023}{\text{Pumping Plant Operating Efficiency}/100} \qquad \text{Eq. (5-4)}$$

The total volume pumped was 169,369 acre-feet. The discharge pressure was assumed to be 50 psi (116 feet). This was based on discussions with local irrigation specialists. The pumping plant operating efficiency was assumed to be 68 percent. Therefore, the energy required for booster pumps for microirrigation in the entire Coachella Valley was as follows:

$$\text{Booster Energy KWH} = \frac{169{,}369 \text{ AF} \times 116 \text{ FT} \times 1.023}{68\%/100} = \mathbf{29{,}556{,}833 \text{ KWH}}$$

Step 6: Energy Used for Lifting Agricultural Groundwater to the Surface in all of Coachella Valley (Total Lift KWH): This component of energy is computed as follows:

Total Lift KWH = Total agricultural pumping energy
- KWH used for boosters on microirrigation systems

Total Lift KWH = 73,059,851 KWH (Step 1)
- 29,556,833 KWH (Step 6)

= 43,503,018 KWH

TABLE 5-3

SUMMARY OF WATER APPLIED TO MICROIRRIGATION FIELDS IN COACHELLA VALLEY (1987)

Crops	Annual ETc (FT)	Total Acreage[1] (AC)	Annual Crop ETc[2] (AF)	Drip Gross Applied[3] (AF)
Grapes	3.3	12,500	41,563	80,940
Citrus	3.8	9,000	33,750	65,725
Dates	6.1	1,000	6,083	11,847
Truck	1.9	3,000	5,575	10,857
Total		25,500		169,369

[1]Source: Coachella Valley Resource Conservation District.

[2]ETc x acreage/12.

[3]Gross = crop water requirement/[65% x (1-0.21)], where 65% = irrigation efficiency and 21% = long-term LR

Step 7. Energy Used for Lifting Agricultural Groundwater to the Surface in CVWD Command Area (Command Lift KWH): This component of energy (Command Lift KWH) is computed as follows:

Command Lift KWH = 43,503,018 KWH (Step 6)
- 24,358,187 KWH (Step 3)

= 19,144,832 KWH

Step 8. Agricultural Groundwater AF pumped in Command Area (Command GW): This volume is computed from the lift energy used (Step 7) by rearranging Equation 5-3.

$$\text{AF Pumped} = \frac{\text{Energy KWH x Pumping Plant Operating Efficiency}}{\text{TDH (FT) x 1.023}} \qquad \text{Eq. (5-5)}$$

The pumping plant efficiency for the deep wells was assumed to be 65 percent. The TDH (total dynamic head) just for lifting was calculated:

TDH = Static Lift (100")
+ Drawdown (20')
+ Minor losses (10')
+ Discharge Pressure (10')
= TDH (inside CVWD command area) = 140 feet

$$\text{Command GW} = \frac{\text{19,144,832 KWH x 65\%/100}}{\text{140 ft x 1.023}} = \underline{\textbf{86,888 AF}}$$

5.4 TOTAL ON-FARM WATER AVAILABILITY IN 1987

A summary of the total water availability for CVWD is shown below for the calendar year 1987.

	On-Farm Deliveries				
	Colorado River Surface Water (AF)	Pumped Groundwater (AF)	Total (AF)	Double-Cropped Irrigated Acres	AF/AC
CVWD (Command Area)	279,000	86,888	365,888	51,386	7.1
Outside Command Area	0	96,730	96,730	14,141	6.8
Entire Coachella Valley	279,000	183,619	462,618	65,527	7.1

Section 6

BENEFICIAL USES OF WATER

The procedure used in this study to estimate irrigation efficiencies requires estimates of evapotranspiration (ET) of each crop. Evapotranspiration includes both evaporation from a wet soil surface plus transpiration (loss of water through the plant leaf stomata).

6.1 METHOD OF ESTIMATING CROP WATER USE

6.1.1 Crop Coefficients and ETo

There are two general sources of published crop ET values:

- o Published data. Published data has a wide range of credibility and accuracy. Much of the published ET data originated from research in which soil moisture changes were measured with time and were equated with crop ET. In some cases, researchers measured applied water and then assumed that some percentage of that applied water was used for crop ET. The accuracy of both procedures depends upon measurement skills and equipment, and assumptions made.

- o Reference crop ET, multiplied by a crop coefficient. Because of the tremendous expense of duplicating field trials to study the crop ET of individual crops in widely differing climatic zones, procedures have been developed to transfer information from one location to another. The general equation of crop ET computation with this method is:

  Daily Crop ET = Kc x (Daily Reference ETo)

  Where:

  Kc is a transferrable "crop coefficient" which can be studied in Israel, for instance, and then used in California. The Kc varies with the stage of growth and the crop type. There are a few instances in which plant physiology prevents a straight transfer of the Kc values between climatic zones. The notable instance in this study is citrus, which has a lower Kc in very dry, arid areas than in less arid areas.

  Reference ET is the ET of an unstressed "reference crop", which has been standardized as grass in most of California and is referred to as "ETo". The ETo value varies daily or hourly with the climate, and is computed rather than measured. The computations in California are based on hourly weather data from the CIMIS network, which is operated by the Office of Water Conservation of the California DWR (OWC/DWR). A transferrable equation is used to compute the ETo at each station in California. In the study area for the years of 1987-1990, the Thermal (Coachella Valley) station was used. The OWC/DWR calculated values of ETo were utilized in these studies.

Older DWR studies estimated ET throughout California based on evaporation pan readings. The evaporation from Class A pans was used as the "reference ET", and special crop coefficients were needed to match the pans. Those older studies provide ET data which conflicts with the newer, more reliable CIMIS ETo values. The average CIMIS ETo for CVWD for 1987-1990 was 73.1 inches (Table 6-1).

The new CIMIS ETo computation techniques have many advantages over the old pan readings, which is why this study utilizes the CIMIS data. A major advantage is the ability of CIMIS to compute hourly ETo and to accurately model hourly crop water use rather than having a single daily value as with a pan, in which case estimates must be made about day versus night computations. In addition, the siting and design of the CIMIS stations is much more uniform than the old pan sites, which provides better quality control. Pan data has long been recognized to have large variations due to different pan locations, pan maintenance, water levels in the pan, and from birds and animals drinking out of the pans. In particular, the "normal year ETo" values published by UC and DWR based on the pan data was derived from pans that were located in nonirrigated sites, which also caused inflated ETo estimates in some desert areas such as the Coachella Valley.

Crop coefficients can be obtained from various sources. Much of the earlier (pre-1985) work on crop coefficients has since been modified, as those coefficients were often developed with either (1) improper field verification, or (2) incorrectly calculated reference crop ET values. This study searched for crop coefficients which were based upon good theory plus which reflected results of good field trials.

For this study, the ET of major crops was computed using CIMIS ETo and proper crop coefficients. Those values were compared with published crop ET values, and the most reasonable value was selected.

Discrepancies in crop ET estimates can also arise from differences in assumptions regarding "unstressed" versus "stressed" crops. In some cases, such as with grapes, growers deliberately stress the crop to induce dormancy. In the case of alfalfa, the ET is not always at maximum because of cutting cycles, planting, and eventual stress for production of seed. This study accounted for the reduced crop ET in the grape case by calculating the seasonal reductions of the Kc values.

This study made wide use of cross-checks of crop ET data and crop ET computations for the major crops in an attempt to arrive at the most reasonable values. Details regarding the major crops are given in this section.

6.1.2 Published Crop ET Data

Evapotranspiration data has been published by the California DWR (Axppendix G) and others for the Coachella Valley. Table 6-2 lists the major crops and various published crop ET values.

TABLE 6-1

CIMIS ETo DATA

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Sum
Thermal (CVWD)													
Cimis No. 50													
1987	2.69	3.62	5.53	8.17	9.02	10.51	9.67	7.69	7.37	4.91	2.61	2.32	74.1
1988	2.53	4.17	6.42	6.88	10.01	9.49	8.44	8.19	7.33	4.72	2.74	2.04	73.0
1989	2.14	3.79	5.60	7.11	8.62	9.08	9.03	8.82	7.33	5.17	3.15	2.15	72.0
1990	2.49	3.60	5.85	7.39	9.29	9.59	9.50	8.08	6.57	5.04	3.56	2.27	73.3
Avg.	2.46	3.80	5.85	7.39	9.24	9.67	9.16	8.20	7.15	4.96	3.02	2.22	**73.1**

Source: DWR CIMIS

TABLE 6-2

PUBLISHED GROWING SEASON ET VALUES

(inches/year)

Crop	Season	DWR[1]	USDA/ARS[2]	Kaddah[3]	Bookman[4]	Oster[5]	T-M[6]
Alfalfa		80.6	80.0	82[7]	66.0	79.1	79.2
Asparagus	3/1-13/15	65.4		55	66.0		69.6
Barley			25.0		24.0	21.7	27.6
Beans							15.6
Beets (table)							0.7
Bermuda grass				50	33.5		
Broccoli							19.2
Cabbage							19.2
Cantaloupe/honeydew							24.0
Carrots	8/15-12/15	16.3	16.6	16	14.4		
Carrots	10/14-3/15	14.9					
Carrots	1/1-5/15	23.9					24.0
Celery							22.8
Corn, sweet	8/1-12/1	21.1	19.6				
Corn, sweet	1/14-5/16	24.2					
Corn, sweet	2/15-6/15	31.7			31.2		30.0
Cotton	4/15-10/15	40.9	41.2	43		40.5	43.2
Dates		68.0			69.6		79.2
Grapes	3/1-10/31	39.9	15.9/19.6		39.6		46.8
Misc. garden crops							22.8
Nursery							36.0
Onions, green	9/15-1/31	13.6	17.5		13.2		13.2
Onions, red/yellow	11/1-5/15	26.0	23.3	23	25.2		30.0
Lettuce	9/15-12/21	12.6	8.3	17	13.2	16.9	
Melons	2/1-6/30	34.3	20.5/16.8		34.8		
Pasture		81.1			81.6		79.2

TABLE 6-2 (continued)

Crop	Season	DWR[1]	USDA/ARS[2]	Kaddah[3]	Bookman[4]	Oster[5]	T-M[6]
Peppers	11/1-5/31	33.5			33.6		30.0
Ryegrass				30			
Sorghum, forge	4/15-11/15	50.5			50.4		
Sorghum, grain	7/1-10/31	24.4	25.4			20.9	
Sorghum, grain	4/1-7/31	30.2		30			
Sudan grass				30		20.9	39.6
Sugarbeets				44	48	45.7	40.8
Tomato, fresh	1/15-5/15	22.1		27	21.6		25.2
Watermelon	1/1-5/31	25.4			25.2		30
Wheat			25.8	25	24.0	25.2	27.6

[1]DWR, 1981.
[2]USDA/ARS, 1982 (Arizona).
[3]Kaddah & Rhodes, 1976 (Imperial).
[4]Bookman-Edmonston, 1989, Table 3 (CVWD). Bookman-Edmonston quoted ET values from a CVWD publication entitled "Water and the Coachella Valley."
[5]Oster et al., 1986 (Imperial).
[6]T-M Case, CVWD Ex. 1059, J.M. Lord.
[7]Kaddah & Rhodes (1976) reported 72 inches of ET for alfalfa, assuming 88% of what could occur due to underirrigation at certain times of the year. The 82" reflects full ET.

6.1.2.1 Notes on Specific Crops - Citrus

The Food and Agriculture Organization (FAO) Irrigation and Drainage Paper 24 "Crop Water Requirements" (Doorenbos and Pruitt, 1977) lists different crop coefficients for various types of citrus, but subsequent research does not justify the use of different coefficients. The Kc values for citrus in the FAO 24 paper were based upon limited sets of older data.

A frequently quoted source of crop ET data which shows differences between various citrus crops is from Arizona (USDA/ARS, 1982). The 1982 date is misleading because this data is based upon very old research done in 1931-34. At that time, there were major problems with estimating crop ET. In particular, the old studies frequently underestimated the magnitude of deep percolation losses.

Wiegand and Swanson (1982) studied crop ET on both grapefruit and orange trees in the Lower Rio Grande Valley of Texas and found that although the crop ET is higher in oranges than grapefruit, the differences are insignificant. They also report that the crop ET is the same for mature citrus under both furrow and drip irrigation.

The CVWD (1990) report recommends a crop coefficient of 0.56 (based on a grass reference) for citrus, with no distinction between lemons, grapefruit, and orange trees.

Dr. David Goldhamer, the horticultural crop irrigation specialist for UC Agricultural Extension, states that the Kc values should be lower in Coachella Valley than in the San Joaquin Valley because of the large stomatal resistance to water movement in citrus leaves.

Van Bavel et al. (1967) did work in arid areas of California and Arizona on orange crop ET, and noted that "it is known that citrus trees transpire less water per unit land area than most common agricultural crops". They credit it to ..."the citrus leaf, as such, to have an uncommonly high resistance." Furthermore, they showed that up to a point of increasing evaporative demand, citrus ET increases. Beyond that point, the ET actually decreases.

Moreshet et al. (1988) found that partial wetting of the root zone of citrus trees, as is done with microirrigation in CVWD, restricted ET by as much as 20 to 30 percent over trees with root zones that were completely wet.

Bielorai (1982) makes the following observations about grapefruit irrigation with drip:

> *The wetted zone supplies water and nutrients to the trees, stimulating growth and production, and results in a saving of water due to reduced evaporation from the non-wetted soil surface area. On the other hand, the continuous and frequent supply of water to the limited soil volume increases the water losses due to percolation below the entire root depth.*

Typical recommendations to increase the Kc for crops under microirrigation are made for crops such as almonds, which traditionally are underirrigated with surface irrigation methods. Furthermore, the continuous wetted soil (under drip) is generally exposed to the sun with deciduous trees (and therefore has a higher evaporation rate) and microsprayers are often used for those crops, increasing the wetted area of the soil. For the Coachella citrus that is drip irrigated, these conditions are not the same. In addition, deciduous trees do not appear to have limitations to ET due to the stomata resistance that citrus has.

Trips through Coachella Valley indicate the following conditions for citrus:

- Very little cover crops, primarily on flood irrigated fields.
- Microirrigation systems primarily wet under the canopy for mature trees.
- Many of the citrus groves are irrigated with furrow irrigation.

Davis et al. (1969) had a unique opportunity to measure citrus crop ET because they used an area near Lake Mathews which essentially acted as a 1000 acre lysimeter. Mature citrus trees during a 5-year period used 30 to 33 inches of water.

Various annual citrus ET values have been published for the desert areas of California. Table 6-3 compares some of the values which are cited.

Conclusion: The 0.56 Kc recommended by both Coachella Valley WD (1990) and University of California (1989) is correct for the desert conditions. This provides an ET of 40.9 inches. However, there is possibility of higher soil evaporation losses with microirrigation even though most CVWD systems wet below the canopy. To take a conservative approach, this study uses:

Annual citrus ET = 45 inches/yr

6.1.2.2 <u>Notes on Specific Crops - Grapes</u>

Rudy Neja (1990) who is the grape specialist for UC in the CVWD area, reported in the "Farm Water Watch," a publication of the CVWD, that the recommended Kc values for post harvest are:

July: 0.45 to 0.50

August: 0.50 to 0.55

September: 0.45 to 0.50

In other words, the Kc for this 3-month period should be 0.50. These values reflect the standard practice of forcing the grapes into dormancy by drying out the soil.

TABLE 6-3

VARIOUS REFERENCED CITRUS CROP ETc VALUES

Source	Crop ETc (in.)	Comments
CVWD, 1990	40.9	Uses Kc = 0.56 and CIMIS ETo value of 73.1 inches for 4 years (1987-90) for Coachella
Davis et al., 1969	30-33	Lake Mathews near Riverside. 1,000-acre lysimeter.
Bookman-Edmonston, 1989	45.6	Taken from a CVWD publication. Same for all types of citrus.
JM Lord, 1992?	49.2	CVWD Exhibit 1059, T-M court case, 1992.
Kaddah & Rhodes, 1976	45	
USDA/ARS, 1982	47.9	Grapefruit. 1931-34 data. Research in Arizona.
USDA/ARS 1982	39.1	Navel oranges. 1931-34 data. Research in Arizona.
Hilgeman, et al., 1969	49.7	Valencia oranges in central Arizona.
California DWR, 1981	46.7	Does not distinguish between various types of citrus. Used as guidelines by the Coachella Valley RCD.

The University of California (1989) lists Kc values of:

Kc1 - 0.27 (leaf out)

Kc2 - 0.82 (maximum canopy)

Kc3 - 0.34 (end of season)

This is for nonstressed grapes, but maximum production of table grapes requires some stressing. Also, as noted above in CVWD, growers have long forced the grapes into dormancy.

Pritchard et al. (1991) recommend a grape ET of about 67 percent of potential grape ET. In the San Joaquin Valley, this means about 18 inches of ET rather than 27 inches of ET. Although the research concentrated on wine grapes, similar results were obtained for table grapes.

In Coachella Valley, it is now common to sprinkle grapevines in the winter, starting at about November 1 at a rate of 40 gpm/acre. Growers irrigate for 6 weeks, starting at 10 a.m. This enables them to harvest 1 week early by increasing the accumulated cold degree-hours so that the vines break dormancy earlier. Some people have done this for 20 years. However, it is a relatively new procedure for most grape growers. In 1987, the acreage with this practice was small. Therefore, such water use is not included as "beneficial use" in this study for 1987. It should also be noted that farmers are probably irrigating much more than needed for climate control. Temperature control can be done most effectively with relatively short pulses of sprinklers. In general, one only needs to apply water 1/6 - 1/7th of the time. This gives the maximum benefit from evaporative cooling. The hand-move sprinkler systems that are currently used for grape climate modification are not set up for this frequent pulsing management.

Conclusions. The grape Kc values, based on CVWD grower practices, are:

- Leaf-out March 1 (Kc = .27)
- Full canopy May 1 (Kc = .82)
- Continue a Kc of .82 until post-harvest drydown begins (July 1)
- Kc drops steadily until 0.5 is reached on July 20.
- Kc remains at 0.5 until Oct. 1
- Significant ET terminates on Nov. 1 (Kc = .34).

These values produce an annual grape ET in CVWD of 37.9 inches which is very close to the published values of 39.9 inches (DWR, 1981; Bookman-Edmonston, 1989).

Annual grape ET in CVWD = 39.9"

6.1.3 Summary of Crop ET Values

The summary of the crop ET values for the Coachella Valley is shown in Table 6-4. The ETo used was averaged for years 1987 through 1990.

6.2 ESTIMATED CROP WATER REQUIREMENT

Table 6-5 shows the calculation of the crop water requirement for the Coachella Valley. The totals are separated by the area within the CVWD command area and the outside of the CVWD command area. The crop water requirement for the CVWD command area was estimated to be 174,000 (rounded) acre-feet.

6.3 ESTIMATED LONG-TERM LEACHING REQUIREMENT

In arid or semi-arid conditions, rainfall is less than what a crop will use during a growing season. Therefore, irrigation is required. As crops remove water from the soil, salts from the irrigation water are left behind. Water from the Colorado River carries a salt loading that has ranged between 0.8 to 1.3 tons per acre-foot of water. This requires salt management by the growers of the Coachella Valley. Some plants, such as lettuce, are "salt-sensitive". Other crops, such as cotton, are "salt-tolerant". The leaching requirement (LR) is used to compute the amount of additional water that must be applied to remove harmful salts from the root zone.

Plants can withstand salinity levels up to derived "threshold" values without decreasing crop yields. Most published crop tolerance levels were developed using artificially salinized soil with a high leaching fraction to produce a uniform soil salinity in moderate climates. The published threshold values may be too high for use in the Coachella Valley due to the extreme climate and high temperatures, and therefore they underestimate the amount of leaching water needed. Salinity impacts are greater with higher temperatures. However, it is not clear how to adjust the values for these conditions.

When analyzing the LR of an area, the typical approach was to individually analyze the crops being grown and obtain the published threshold values for each crop. However, this approach ignores the fact that growers are increasing the utilization of crop rotations. If a grower wishes to modify the cropping pattern from alfalfa to a vegetable crop, the soil salinity must be low enough to allow the most salt-sensitive crop in the rotation to survive without yield declines. If the crop rotation includes a crop with a low salt tolerance, the field must be maintained at the lower level. Otherwise rotation would not be possible. The long-term rotation must be considered in determining the correct LR to apply. This does not apply to permanent crops. The traditional approach must be used. Refer to Appendix H for a detailed analysis of the long-term LR approach. Table 6-6 is a listing of the threshold salinities of several of the typical crops grown. The salinity of the soil (ECe) defines for the grower the types of crops to be grown. The required LR can best be estimated by using the following equation:

$$\text{Leaching Requirement} = \frac{(ECw)}{(5*ECe - ECw)} \qquad \text{Eq. (6-1)}$$

TABLE 6-4

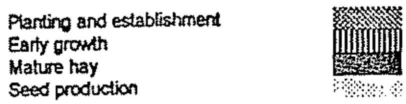
SUMMARY CVWD CROP ETc VALUES

Source	Annual ETc (in.)	Comments
Alfalfa	70.1	Kc-computed accounting for 3, 4, or 5-year crop with seed at end; Kc's adjusted for cutting. See Figure 6-1.
Broccoli	14.3	Kc-computed.
Carrots	21.0	Kc-computed. Middle of range for DWR (1981) report; higher than others. Accounts for soil evaporation from sprinklers.
Dates	73.1	Kc-computed (Kc = 1). Slightly higher than 68" by DWR (1981) and 69.6" by B-E (1989).
Grapefruit	45.0	Between various published values. Greater than Kc-computed value of 40.9" to allow for some extra soil wetting.
Grapes	39.9	From DWR, 1981. Similar to B-K, 1989 (39.6") and Kc-computed (37.9").
Lemons	45.0	Between various published values. Greater than Kc-computed value of 40.9" to allow for some extra soil wetting.
Lettuce	15.5	92% of IID value reported by Oster, et al. Higher than DWR (1981) due to accounting for soil evaporation loss.
Mixed Pasture	73.1	Assumes Kc = 1.
Oranges	45.0	Between various published values. Greater than Kc-computed value of 40.9" to allow for some extra soil wetting.
Duck/Fish Ponds	87.7	1.2 times ETo, similar to rice.

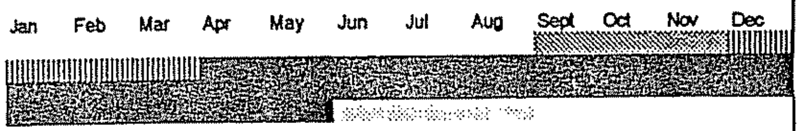
Note: The 1987-90 average CIMIS ETo for Coachella Valley is 73.1 inches.

Summary Alfalfa Crop ETc Calculation

Notes:
Alfalfa is typically grown for either a 3,4, or 5 year crop.
Alfalfa seed is usually produced in the last year of hay production. Hay is harvested until about May 15
and then seed is produced during June, July, and August. Seed is harvested from about August 15 through Sept. 15.
The information above is from B&E (1992), attachment 15, which was produced from statistics supplied by
the Agricultural Service, UC, Imperial Co. Bulliten No. 1075.

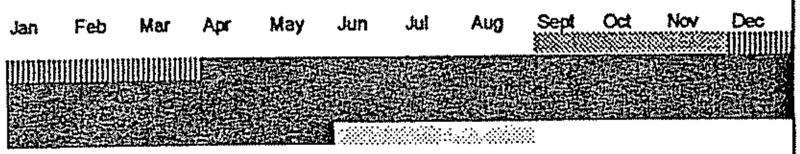


3 Year Crop Growth Pattern



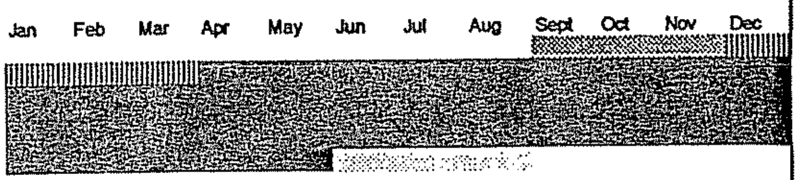
3 Year Crop Kc Values	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
									0.34	0.34	0.50	0.60
	0.70	0.90	1.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.20	1.20
	1.20	1.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.20	1.20
	1.20	1.20	1.00	1.00	1.00	0.90	0.70	0.50				
Average of 3 Year Kc	1.03	1.10	1.07	1.00	1.00	0.97	0.90	0.83	0.78	0.78	0.97	1.00

4 Year Crop Growth Pattern



4 Year Crop Kc Values	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
									0.34	0.34	0.50	0.60
	0.70	0.90	1.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.20	1.20
	1.20	1.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.20	1.20
	1.20	1.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.20	1.20
	1.20	1.20	1.00	1.00	1.00	0.90	0.70	0.50				
Average of 4 Year Kc	1.08	1.13	1.05	1.00	1.00	0.98	0.93	0.88	0.84	0.84	1.03	1.05

5 Year Crop Growth Pattern



5 Year Crop Kc Values	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
									0.34	0.34	0.50	0.60
	0.70	0.90	1.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.20	1.20
	1.20	1.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.20	1.20
	1.20	1.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.20	1.20
	1.20	1.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.20	1.20
	1.20	1.20	1.00	1.00	1.00	0.90	0.70	0.50				
Average of 5 Year Kc	1.10	1.14	1.04	1.00	1.00	0.98	0.94	0.90	0.87	0.87	1.06	1.08

Average of 3 Cycles	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	
Kc	1.07	1.12	1.05	1.00	1.00	0.97	0.92	0.87	0.83	0.83	1.02	1.04	
CVWD ETo	2.46	3.80	5.85	7.39	9.24	9.67	9.16	8.20	7.15	4.96	3.02	2.22	
CVWD Crop ETc - Alfalfa	2.63	4.26	6.16	7.39	9.24	9.42	8.44	7.13	5.92	4.11	3.07	2.32	
												70.08	Total (in)

TABLE 6-5

SUMMARY OF ETc AND ACREAGE FOR CVWD
(Including Double Cropping)

Crops	Annual[1] ETc (IN)	CVWD Command Area Total[2] Acreage (AC)	CVWD Command Area Annual[3] Crop ETc (AF)	Outside CVWD Command Area Total[2] Acreage (AC)	Outside CVWD Command Area Annual[3] Crop ETc (AF)	Total Coachella Valley Total[2] Acreage (AC)	Total Coachella Valley Annual[3] Crop ETc (AF)
Alfalfa	70.1	2,485	14,517	0	0	2,485	14,517
Broccoli	14.3	2,711	3,232	0	0	2,711	3,232
Carrots	21.0	2,711	4,746	156	273	2,867	5,019
Dates	73.1	5,050	30,763	579	3,524	5,629	34,290
Grapefruit	45.0	5,751	21,566	1,861	6,979	7,612	28,545
Grapes	39.9	12,885	42,843	6,188	20,576	19,073	63,418
Lemons	45.0	1,397	5,239	1,031	3,865	2,427	9,105
Lettuce	15.5	3,686	4,761	439	567	4,125	5,327
Mixed pasture	73.1	1,340	8,163	151	920	1,492	9,083
Oranges	45.0	2,849	10,684	392	1,471	3,241	12,154
Ponds - duck/fish	87.7	0	0	988	7,221	988	7,601
Misc. truck	22.3	7,294	13,555	980	1,822	8,275	5,426
Misc. field	32.1	1,811	4,844	1,017	2,719	2,827	22,090
Misc. perm.	37.6	1,416	4,435	359	1,125	1,775	5,559
Total		**51,386**	**169,348**	**14,141**	**51,063**	**65,527**	**220,411**

[1]From Table 6-4.
[2]From Table 5-1.
[3]ET_c x Acreage/12.

TABLE 6-6

SALT TOLERANCE OF SELECTED CROPS

Crop	Threshold ECe	Salt Tolerance
Alfalfa	2.0	MS
Bermuda Grass	6.9	T
Broccoli	2.8	MS
Carrot	1.0	S
Cotton	7.7	T
Date Palm	4.0	T
Grape	1.5	MS
Grapefruit	1.8	S
Lettuce	1.3	MS
Onion	1.2	S
Orange	1.7	S
Sugarbeet	7.0	T
Tomato	2.5	MS

Reference: Maas and Hoffman, 1977. ECe equals the soil salinity at which point a yield decline is expected in dS/m. S - Sensitive, MS = Moderately Sensitive, MT = Moderately Tolerant, and T = Tolerant (Note: 1 dS/m = 1 mmho/cm).

Based on a long-term required ECe of 1.5 dS/m and water quality of the Colorado River of 1.3 dS/m (long-term high), the LR was estimated to be 0.21 {1.3/[(5*1.5)-1.3]} or 21%. This value is easily attainable in the Coachella Valley due to the coarser, sandy soils.

The leaching fraction represents the amount of actual leaching that occurs during the growing season. The excess water percolates through the root zone to move salts to lower depths. In the CVWD where soils are coarse and sands, the LF was estimated equal the LR.

6.4 ESTIMATED EFFECTIVE RAIN

The amount of rainfall in a year that can actually be used by the crops is the effective rainfall. During 1987, the majority of the volume of rain fell in the winter months which most crops could utilize. However, the light rain resulted in a high percentage of nonbeneficial evaporation loss from the soil surface. Therefore, in this analysis effective precipitation was calculated based on the entire acreage receiving about 30% of the total rain as effective precipitation. Table 6-7 is a summary of the total rainfall in 1987. In order to calculate the net benefit of the rainfall, the actual acreage in production during the growing season was used. This removes the acreage due to double cropping.

In CVWD, the net irrigated acreage without double cropping was 42,280 (Table 5-1) acres. The amount of total rainfall was 4.26 inches (Table 6-7). The calculated value for the effective rainfall in the CVWD command area during 1987 was 4,500 (rounded) acre-feet.

6.5 IRRIGATION EFFICIENCY

The irrigation efficiency was determined using the amount of water delivered to the individual farmers and is the same equation as Equation 3-3. This equation does not account for distribution uniformity. This equation also does not account for runoff water that may be accounted for as beneficial water due to environmental regulation. The variables were generated in the following sections. Crop ETc was generated in Section 6.1.3, effective rain (Section 6.4), delivered water (Section 5.4), and leaching requirement (Section 6.3).

$$\text{On-Farm Irrigation Efficiency} = \frac{\text{Crop ETc - Effective Rain}}{(\text{Delivered Water}) \times (1\text{-LR})} \qquad \text{Eq. (6-2)}$$

For the CVWD command area, the crop ETc was computed to be 169,348 acre-feet. The effective rain was 4,580 acre-feet. The applied water was 365,888 acre-feet (includes 279,000 acre-feet of surface supplies and 86,888 acre-feet of groundwater supplies from Section 5.4). The beneficial leaching requirement was estimated at 21%.

$$\text{CVWD Command Area On-Farm Irrigation Efficiency} = \frac{169{,}348 - 4{,}580}{(365{,}888) \times (1-.21)} = 0.57 \text{ or } 57\%$$

TABLE 6-7

SUMMARY OF TOTAL RAINFALL IN 1987

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
Mecca FS	0.00	0.28	0.14	0.00	0.00	0.00	0.00	0.05	0.14	1.31	2.08	0.58	4.58
Thermal FAA AP	0.15	0.27	0.18	0.00	0.00	0.00	0.03	0.11	0.08	1.53	0.94	0.65	3.94
Average	0.08	0.28	0.16	0.00	0.00	0.00	0.02	0.08	0.11	1.42	1.51	0.62	**4.26**

Source: National Oceanic and Atmospheric Administration (NOAA).

Section 7

FINDINGS AND CONCLUSIONS

This report evaluated the on-farm irrigation efficiency of the CVWD command area. The approach used was based primarily on the generation of a theoretical crop ETc. The following were the significant findings of this study.

- o Agricultural groundwater pumping volumes in Coachella Valley have not been investigated and reported thoroughly in previous reports.

- o Electrical power records were separable for agricultural pumping energy use (PA rate).

- o Acreage figures from the DWR showed a significant amount of irrigated acreage outside of the CVWD surface water facilities boundaries (command area). This acreage was accounted for in this report by plotting the CVWD service boundary onto the DWR quad sheets and accounting for the acreage inside/outside of the command area.

- o The CVWD command area acreage, annual PA (agricultural pumping) electrical use, and estimates of booster pumping were used to determine an estimate of groundwater pumping within the CVWD command area. The estimate is about 87,000 acre-feet of groundwater pumping from within the command area. This compares to a reported value of 34,400 acre-feet for the command area by CVWD in 1987.

- o Computed annual ETo in 1987-1990 for Coachella Valley was 73.1 inches from the published data by CIMIS.

- o Measured distribution uniformity in CVWD average 76 percent for microirrigation systems. Other irrigation system types are considered to have lower uniformities in the Coachella Valley due to the coarse soils. The on-farm irrigation efficiency must be lower than the measured DU since significant underirrigation is not shown to be occurring.

- o This report advocates the use of a long-term leaching requirement. The long-term leaching requirement was determined to be equal to the leaching fraction at 21 percent of applied water in CVWD command area. The assumed long-term soil salinity was 1.5 dS/m. The water quality of the Colorado River was assumed to be 1.3 dS/m for the leaching requirements calculation.

- o The effective precipitation was assumed to be 30 percent of the total rainfall during 1987. The total rainfall was 4.26 inches in CVWD. The amount of rainfall treated as effective was 1.28 inches for CVWD.

- The calculated on-farm irrigation efficiency of the CVWD command area was 57 percent in 1987. This on-farm irrigation efficiency estimate was determined using the method of theoretical crop ETc.

APPENDIX A

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APPENDIX B

CVWD - DATABASE SORT BY USGS QUADRANGLE

USGS 7.5 MINUTE QUADRANGLE (1)	CODE (2)	UNIT (3)	LAND USE SYMBOL 1 (4)	2 (5)	3 (6)	COACHELLA VALLEY IRRIGATED AGRICULTURAL ACRES (7)	GROSS IRR. AG ACREAGE OUTSIDE OF CVWD SUPPLY (8)	GROSS CVWD COMMAND ACREAGE IRRIGATED (9)
MYOMA	6666	33	F		F	5	0	5
			F6			10	10	0
			P3			72	67	5
			T		F	193	116	77
			T2			113	113	0
			T9			29	29	0
			T23			7	7	0
			C1			573	539	34
			C3			92	92	0
			C4			108	108	0
			C7			2	2	0
			V			911	827	84
			V		A	21	21	0
			I1			6	6	0
			C4	C7		2	2	0
SUBTOTAL						2,144		205
WEST BERDOO CANYON	6667	33	T		F	227		227
			T2			86		86
			T8			82		82
			T14			29		29
			T23			55		55
			C1			336	22	314
			C3			28		28
			C3	C4		16		16
			C3	C4	Y	19		19
SUBTOTAL						878		856
LA QUINTA	6766	33	F		T	53	53	0
			P1			47		47
			P3			130		130
			P7			20	20	0
			T		F	29	29	0
			T		T	10		10
			T9			3		3
			T10			5		5
			T14			3		3
			T16			2		2
			T18			7	7	0
			T22			7		7
			D5			131		131
			C1			872	60	812
			C1		A	15	15	0
			C2			12		12
			C3			95	18	77
			C4			327	180	147
			C4		A	15	15	0
			C6			7		7
			C7			1		1
			I1			237		237
			C2	C3		21		21
			C1	C4		32		32
			C3	C4		56	32	24
SUBTOTAL						2,137		1,708
INDIO			F		F	53		53
			F		Z	41		41
			F1			177		177
			P		F	281		281
			P1			1,416		1,416
			P3			575		575
			P7			148		148
			T		F	1,338		1,338
			T		T	217		217
			T		Z	55		55
			T2			229		229
			T4			29		29
			T6			532		532
			T7			8		8
			T8			604		604

CVWD - DATABASE SORT BY USGS QUADRANGLE

USGS 7.5 MINUTE QUADRANGLE (1)	CODE (2)	UNIT (3)	LAND USE SYMBOL 1 (4)	2 (5)	3 (6)	COACHELLA VALLEY IRRIGATED AGRICULTURAL ACRES (7)	GROSS IRR. AG ACREAGE OUTSIDE OF CVWD SUPPLY (8)	GROSS CVWD COMMAND ACREAGE IRRIGATED (9)
			T9			30		30
			T10			51		51
			T11			3		3
			T14			125		125
			T15			16		16
			T16			203		203
			T18			128		128
			T22			324		324
			T23			128		128
			D		Y	9		9
			C		A	5	5	0
			C		Y	96		96
			C1			1.110	110	1.000
			C1		Y	21		21
			C2			25	10	15
			C3			308	68	240
			C4			1.981		1.981
			C4		A	12	12	0
			C4		Y	187		187
			C7			24		24
			V			1,794	19	1,775
			I1			271		271
			C1	C4		379		379
			C2	C4		19		19
SUBTOTAL						12,952		12,728
THERMAL CANYON			F		F	109		109
			P		F	5		5
			P1			7		7
			P3			11		11
			T		F	12		12
			C		Y	2		2
			C1			227		227
			C2			287	23	264
			C3		Y	39		39
			C4			110		110
			V			2,365	279	2,086
			I1			42		42
			I2			39		39
			C2	C4		22		22
SUBTOTAL						3,277		2,975
MARTINEZ MOUNTAIN	6866	33	P1			178		178
			T16			2		2
			C1			4		4
			C4			15		15
SUBTOTAL						199		199
VALERIE	6867	33	G			103		103
			F		F	378		378
			F1			592		592
			F1		F	103		103
			P		F	177		177
			P1			856		856
			P3			334		334
			T		F	1,929		1,929
			T		T	326	90	236
			T		Z	195		195
			T3			8	8	0
			T4			23		23
			T6			726	41	685
			T8			861	95	766
			T9			168	39	129
			T10			86		86
			T14			28		28
			T16			95		95
			T18			307		307
			T22			854		854
			T23			37		37
			T24			184		184
			D			31		31

CVWD - DATABASE SORT BY USGS QUADRANGLE

USGS 7.5 MINUTE QUADRANGLE (1)	CODE (2)	UNIT (3)	LAND USE SYMBOL 1 (4)	2 (5)	3 (6)	COACHELLA VALLEY IRRIGATED AGRICULTURAL ACRES (7)	GROSS IRR AG ACREAGE OUTSIDE OF CVWD SUPPLY (8)	GROSS CVWD COMMAND ACREAGE IRRIGATED (9)
			D		Y	9	9	0
			D13			10		10
			C		Y	119		119
			C1			1,753	496	1,257
			C2			399	160	239
			C3			446	64	382
			C4			1,621		1,621
			C4		Y	139		139
			V			5,036	2346	2,690
			I1			254		254
SUBTOTAL						18,187		14,839
MECCA	6868	33	F1		F	84		84
			F6			40		40
			P		F	11		11
			P1			102		102
			P3			200		200
			T		F	2,016	187	1,829
			T		T	270	103	167
			T6			251	41	210
			T8			508	127	381
			T8		F	10		10
			T9			101	4	97
			T10			82		82
			T14			17		17
			T18			16		16
			T21			80		80
			T22			215		215
			T23			64		64
			T24			39		39
			D		Y	39		39
			D9			7		7
			C		Y	300	33	267
			C1			1,852	617	1,235
			C1		Y	48	33	15
			C2			960	118	842
			C2		Y	9		9
			C3			1,348	144	1,204
			C3		Y	85	85	0
			C4			631	43	588
			C4		Y	13		13
			V			5,736	801	4,935
			I1			309	124	185
SUBTOTAL						15,443		12,983
MORTMAR	6869	33	T9			12		12
			T21			157		157
			D			24		24
			C		Y	32		32
			C1			61	6	55
			C2			3		3
			C3			472		472
			C4			54		54
			V			803	44	759
SUBTOTAL						1,618		1,568
RABBIT PEAK			T		F	19		19
			T		T	119		119
			T8			24		24
			T10			42		42
			T18			6		6
			T20			18		18
			T22			14		14
			T23			2		2
			C		Y	9		9
			C1			68		68
			C2			694	650	44
			C3			80		80
			C4			111	41	70
			C4		Y	18		18
			V			842	683	159

CVWD - DATABASE SORT BY USGS QUADRANGLE

USGS 7.5 MINUTE QUADRANGLE (1)	CODE (2)	UNIT (3)	LAND USE SYMBOL 1 (4)	2 (5)	3 (6)	COACHELLA VALLEY IRRIGATED AGRICULTURAL ACRES (7)	GROSS IRR. AG ACREAGE OUTSIDE OF CVWD SUPPLY (8)	GROSS CVWD COMMAND ACREAGE IRRIGATED (9)
			V		A	30	30	0
SUBTOTAL						2,096		692
OASIS			P		F	9		9
			P1			10		10
			P3			8		8
			T		F	221	9	212
			T		T	42		42
			T8			92	9	83
			T9			37	37	0
			T10			60	29	31
			T16			69	18	51
			T18			30		30
			T22			13		13
			T23			3		3
			T24			51	24	27
			D		Y	4		4
			C		A	18	18	0
			C		Y	244	176	68
			C1			1,157	109	1,048
			C1		Y	21	12	9
			C2			154	124	30
			C3			543	27	516
			C3		Y	48		48
			C4			241	22	219
			C4		Y	138	26	112
			V			2,590	1515	1,075
			I1			56		56
SUBTOTAL						5,859		3,704
OTHER QUADS	6665	33	C4			139	139	0
			C4		A	4	4	0
	6673	33	F10			472	472	0
	6765	33	C4			44	44	0
	6563	33	P3			72	72	0
	6565	33	T16			8	8	0
			C2		A	11	11	0
SUBTOTAL						750		0
TOTALS						65,540	13,083	52,457

APPENDIX C

CVWD - 1987 DATABASE SORT BY CROP

CROP (1)	LAND USE SYMBOL 1 (2)	2 (3)	3 (4)	COACHELLA VALLEY IRRIGATED AGRICULTURAL ACRES (5)	GROSS IRR. AG ACREAGE OUTSIDE OF CVWD SUPPLY (6)	GROSS CVWD COMMAND ACREAGE IRRIGATED (7)
Citrus-Abandoned	C		A	5	5	0
	C		A	18	18	0
				23	**23**	**0**
Citrus-Young	C		Y	96		96
	C		Y	2		2
	C		Y	119		119
	C		Y	300	33	267
	C		Y	32		32
	C		Y	9		9
	C		Y	244	176	68
				802	**209**	**593**
Grapefruit/Dates	C1	C4		32		32
	C1	C4		379		379
				411	**0**	**411**
Grapefruit-Abandoned	C1		A	15	15	0
				15	**15**	**0**
Grapefruit-Young	C1		Y	21		21
	C1		Y	48	33	15
	C1		Y	21	12	9
				90	**45**	**45**
Grapefruit	C1			573	539	34
	C1			336	22	314
	C1			872	60	812
	C1			1,110	110	1,000
	C1			227		227
	C1			4		4
	C1			1,753	496	1.257
	C1			1,852	617	1,235
	C1			61	6	55
	C1			68		68
	C1			1,157	109	1,048
				8,013	**1,959**	**6,054**
Lemons/Oranges	C2	C3		21		21
				21		**21**
Lemons/Dates	C2	C4		19		19
	C2	C4		22		22
				41	**0**	**41**
Lemons-Abandoned	C2		A	11	11	
				11	**11**	**0**
Lemons-Young	C2		Y	9		9
				9		**9**
Lemons	C2			12		12
	C2			25	10	15
	C2			287	23	264
	C2			399	160	239
	C2			960	118	842
	C2			3		3
	C2			694	650	44
	C2			154	124	30
				2,534	**1,085**	**1,449**
Oranges/Dates	C3	C4	Y	19		19
				19		**19**
Oranges/Dates	C3	C4		16		16
	C3	C4		56	32	24
				72	**32**	**40**
Oranges-Young	C3		Y	39		39
	C3		Y	85	85	0
	C3		Y	48		48
				172	**85**	**87**

CVWD - 1987 DATABASE SORT BY CROP

CROP (1)	LAND USE SYMBOL 1 (2)	2 (3)	3 (4)	COACHELLA VALLEY IRRIGATED AGRICULTURAL ACRES (5)	GROSS IRR. AG ACREAGE OUTSIDE OF CVWD SUPPLY (6)	GROSS CVWD COMMAND ACREAGE IRRIGATED (7)
Oranges	C3			92	92	0
	C3			28		28
	C3			95	18	77
	C3			308	68	240
	C3			446	64	382
	C3			1,348	144	1.204
	C3			472		472
	C3			80		80
	C3			543	27	516
				3,412	**413**	**2,999**
Dates/Miscellaneous	C4	C7		2	2	
				2	**2**	**0**
Dates-Abandoned	C4		A	15	15	0
	C4		A	12	12	0
	C4		A	4	4	0
				31	**31**	**0**
Dates-Young	C4		Y	187		187
	C4		Y	139		139
	C4		Y	13		13
	C4		Y	18		18
	C4		Y	138	26	112
				495	**26**	**469**
Dates	C4			108	108	0
	C4			327	180	147
	C4			1,981		1,981
	C4			110		110
	C4			15		15
	C4			1,621		1,621
	C4			631	43	588
	C4			54		54
	C4			111	41	70
	C4			241	22	219
	C4			139	139	0
	C4			44	44	0
				5,382	**577**	**4,805**
Olives	C6			7		7
				7		**7**
Miscellaneous	C7			2	2	0
	C7			1		1
	C7			24		24
				27	**2**	**25**
Deciduous-Young	D		Y	9		9
	D		Y	9	9	0
	D		Y	39		39
	D		Y	4		4
				61	**9**	**52**
Deciduous	D			31		31
	D			24		24
				55	**0**	**55**
Walnuts	D13			10		10
				10		**10**
Peaches	D5			131		131
				131		**131**
Figs	D9			7		7
				7		**7**
Fallow	F		F	5	0	5
	F		F	53		53
	F		F	109		109
	F		F	378		378
	F1		F	103		103

CVWD - 1987 DATABASE SORT BY CROP

CROP (1)	LAND USE SYMBOL 1 (2)	2 (3)	3 (4)	COACHELLA VALLEY IRRIGATED AGRICULTURAL ACRES (5)	GROSS IRR. AG ACREAGE OUTSIDE OF CVWD SUPPLY (6)	GROSS CVWD COMMAND ACREAGE IRRIGATED (7)
	F1		F	84		84
				732	**0**	**732**
Field Crops-Tilled	F		T	53	53	
				53	**53**	**0**
Field Crops-Reclamation	F		Z	41		41
				41		**41**
Cotton	F1			177		177
	F1			592		592
				769	**0**	**769**
Beans	F10			472	472	
				472	**472**	**0**
Corn	F6			10	10	0
	F6			40		40
				50	**10**	**40**
Grain	G			103		103
				103		**103**
Idle	I1			6	6	0
	I1			237		237
	I1			271		271
	I1			42		42
	I1			254		254
	I1			309	124	185
	I1			56		56
				1,175	**130**	**1,045**
Idle	I2			39		39
				39		**39**
Fallow	P		F	281		281
	P		F	5		5
	P		F	177		177
	P		F	11		11
	P		F	9		9
				483	**0**	**483**
Alfalfa	P1			47		47
	P1			1,416		1,416
	P1			7		7
	P1			178		178
	P1			856		856
	P1			102		102
	P1			10		10
				2,616	**0**	**2,616**
Pasture	P3			72	67	5
	P3			130		130
	P3			575		575
	P3			11		11
	P3			334		334
	P3			200		200
	P3			8		8
	P3			72	72	0
				1,402	**139**	**1,263**
Turf Farms	P7			20	20	0
	P7			148		148
				168	**20**	**148**
Fallow	T		F	193	116	77
	T		F	227		227
	T		F	29	29	0
	T		F	1,338		1,338
	T		F	12		12

CVWD - 1987 DATABASE SORT BY CROP

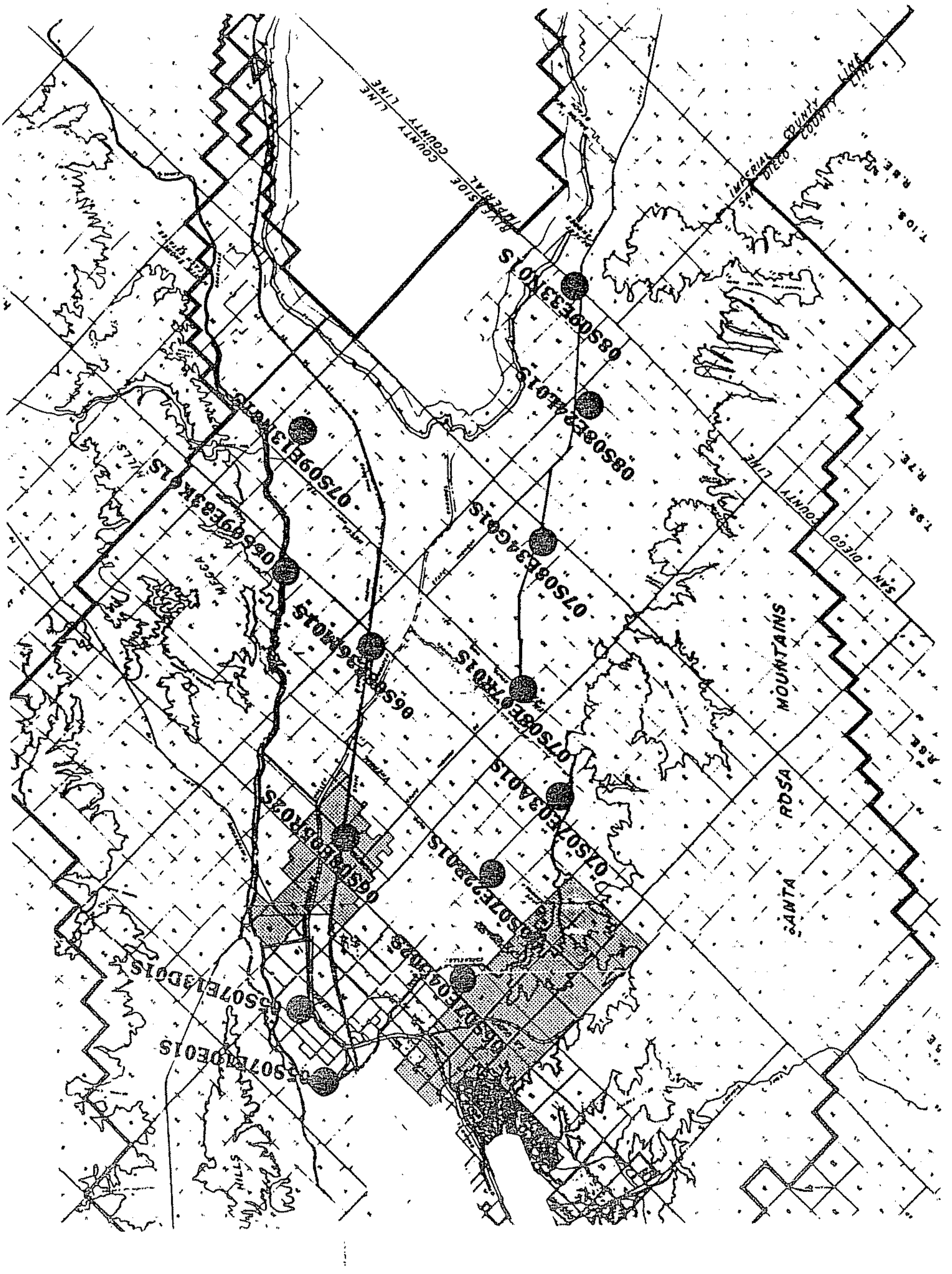
CROP (1)	LAND USE SYMBOL 1 (2)	2 (3)	3 (4)	COACHELLA VALLEY IRRIGATED AGRICULTURAL ACRES (5)	GROSS IRR. AG ACREAGE OUTSIDE OF CVWD SUPPLY (6)	GROSS CVWD COMMAND ACREAGE IRRIGATED (7)
	T		F	1,929		1,929
	T		F	2,016	187	1,829
	T		F	19		19
	T		F	221	9	212
	T8		F	10		10
				5,994	**341**	**5,653**
Truck-Tilled	T		T	10		10
	T		T	217		217
	T		T	326	90	236
	T		T	270	103	167
	T		T	119		119
	T		T	42		42
				984	**193**	**791**
Tuck-Reclamation	T		Z	55		55
	T		Z	195		195
				250	**0**	**250**
Onions	T10			5		5
	T10			51		51
	T10			86		86
	T10			82		82
	T10			42		42
	T10			60	29	31
				326	**29**	**297**
Peas	T11			3		3
				3		**3**
Spinach	T14			29		29
	T14			3		3
	T14			125		125
	T14			28		28
	T14			17		17
				202	**0**	**202**
Tomatoes	T15			16		16
				16		**16**
Flowers	T16			2		2
	T16			203		203
	T16			2		2
	T16			95		95
	T16			69	18	51
	T16			8	8	0
				379	**26**	**353**
Misc. Truck	T18			7	7	0
	T18			128		128
	T18			307		307
	T18			16		16
	T18			6		6
	T18			30		30
				494	**7**	**487**
Asparagus	T2			113	113	0
	T2			86		86
	T2			229		229
				428	**113**	**315**
Strawberries	T20			18		18
				18		**18**
Peppers	T21			80		80
	T21			157		157
				237	**0**	**237**
Broccoli	T22			7		7
	T22			324		324

CVWD - 1987 DATABASE SORT BY CROP

CROP (1)	LAND USE SYMBOL 1 (2)	2 (3)	3 (4)	COACHELLA VALLEY IRRIGATED AGRICULTURAL ACRES (5)	GROSS IRR. AG ACREAGE OUTSIDE OF CVWD SUPPLY (6)	GROSS CVWD COMMAND ACREAGE IRRIGATED (7)
	T22			854		854
	T22			215		215
	T22			14		14
	T22			13		13
				1,427	0	1,427
Cabbage	T23			7	7	0
	T23			55		55
	T23			128		128
	T23			37		37
	T23			64		64
	T23			2		2
	T23			3		3
				296	7	289
Cauliflower	T24			184		184
	T24			39		39
	T24			51	24	27
				274	24	250
Beans	T3			8	8	
				8	8	0
Cole Crops	T4			29		29
	T4			23		23
				52	0	52
Carrots	T6			532		532
	T6			726	41	685
	T6			251	41	210
				1,509	82	1,427
Celery	T7			8		8
				8		8
Lettuce	T8			82		82
	T8			604		604
	T8			861	95	766
	T8			508	127	381
	T8			24		24
	T8			92	9	83
				2,171	231	1,940
Melons	T9			29	29	0
	T9			3		3
	T9			30		30
	T9			168	39	129
	T9			101	4	97
	T9			12		12
	T9			37	37	0
				380	109	271
Abandoned	V		A	21	21	0
	V		A	30	30	0
				51	51	0
Vineyards	V			911	827	84
	V			1,794	19	1,775
	V			2,365	279	2,086
	V			5,036	2346	2,690
	V			5,736	801	4,935
	V			803	44	759
	V			842	683	159
	V			2,590	1515	1,075
				20,077	6,514	13,563
Totals				65,540	13,083	52,457

APPENDIX D

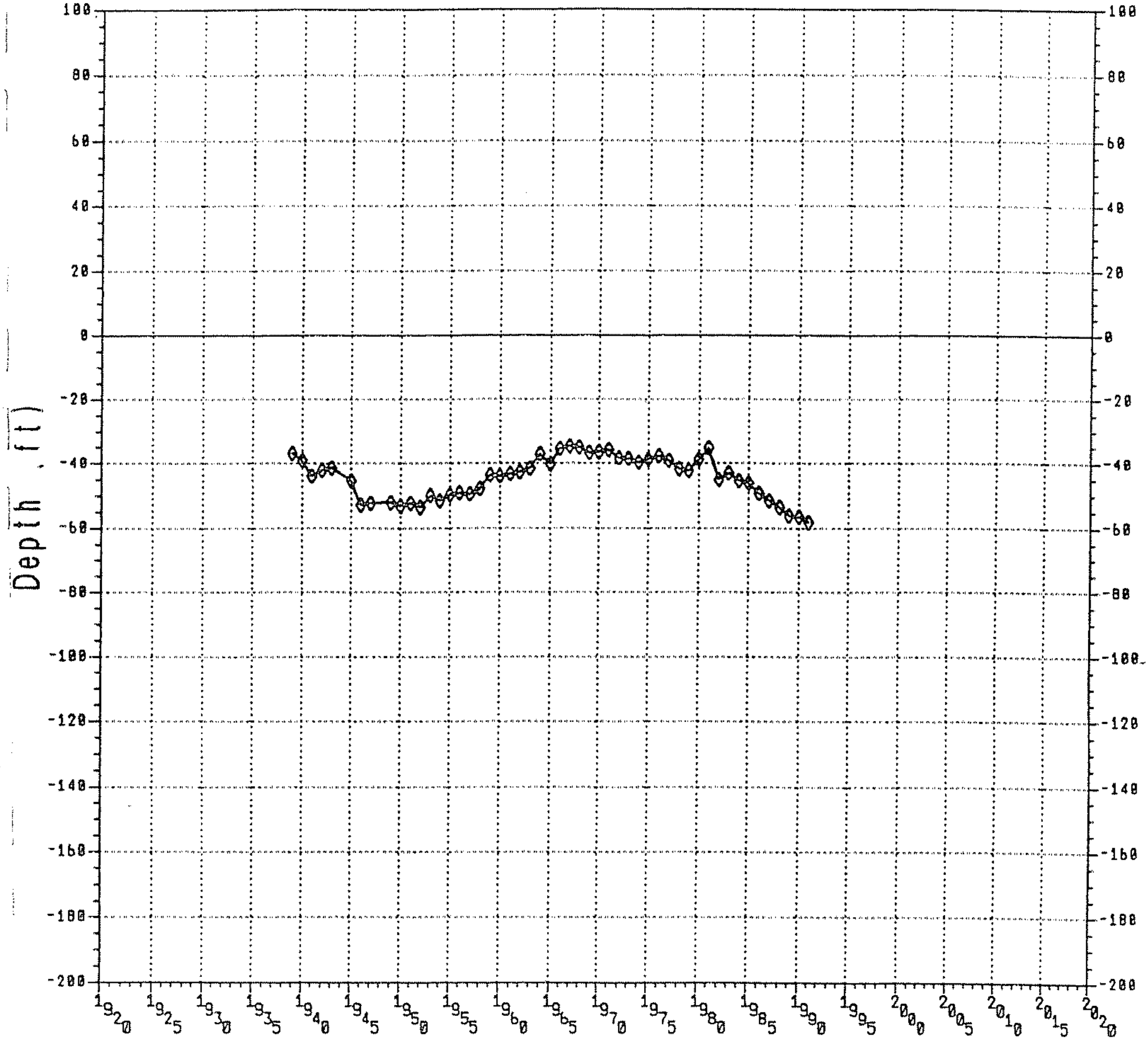
REFERENCE: CVWD TM CASE EXHIBIT 1044



Coachella Valley Water District

AVERAGE ANNUAL DEPTH from GROUND SURFACE

Well: 05S07E10E01S



Basin: INDIO

Area : THERMAL

Perforation Depth (ft)

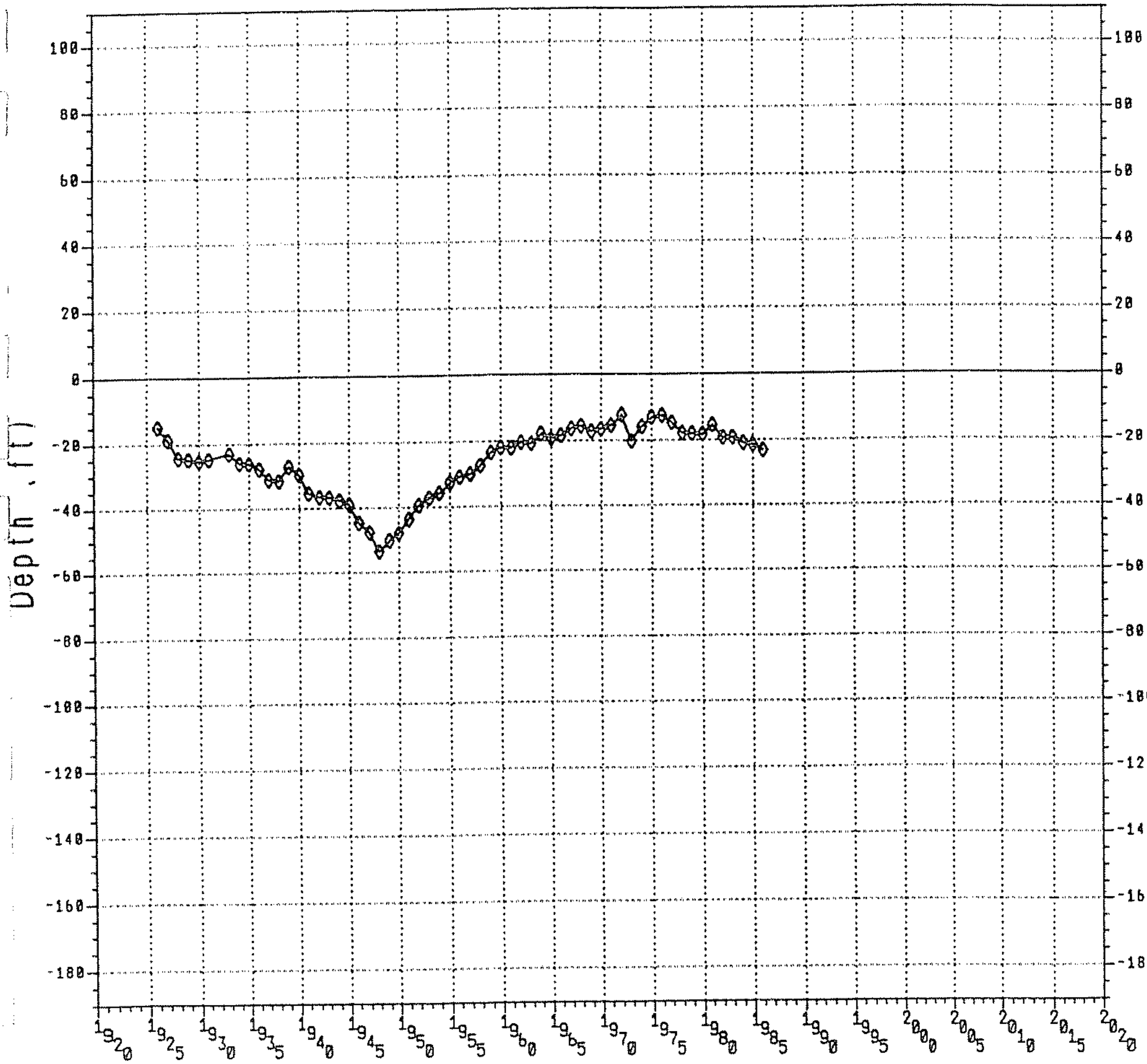
70 - 360

ws: B4 User: RR120186

Coachella Valley Water District

AVERAGE ANNUAL DEPTH from GROUND SURFACE

Well: 05S07E13D01S



Basin: INDIO

Area : THERMAL

Perforation Depth (ft)

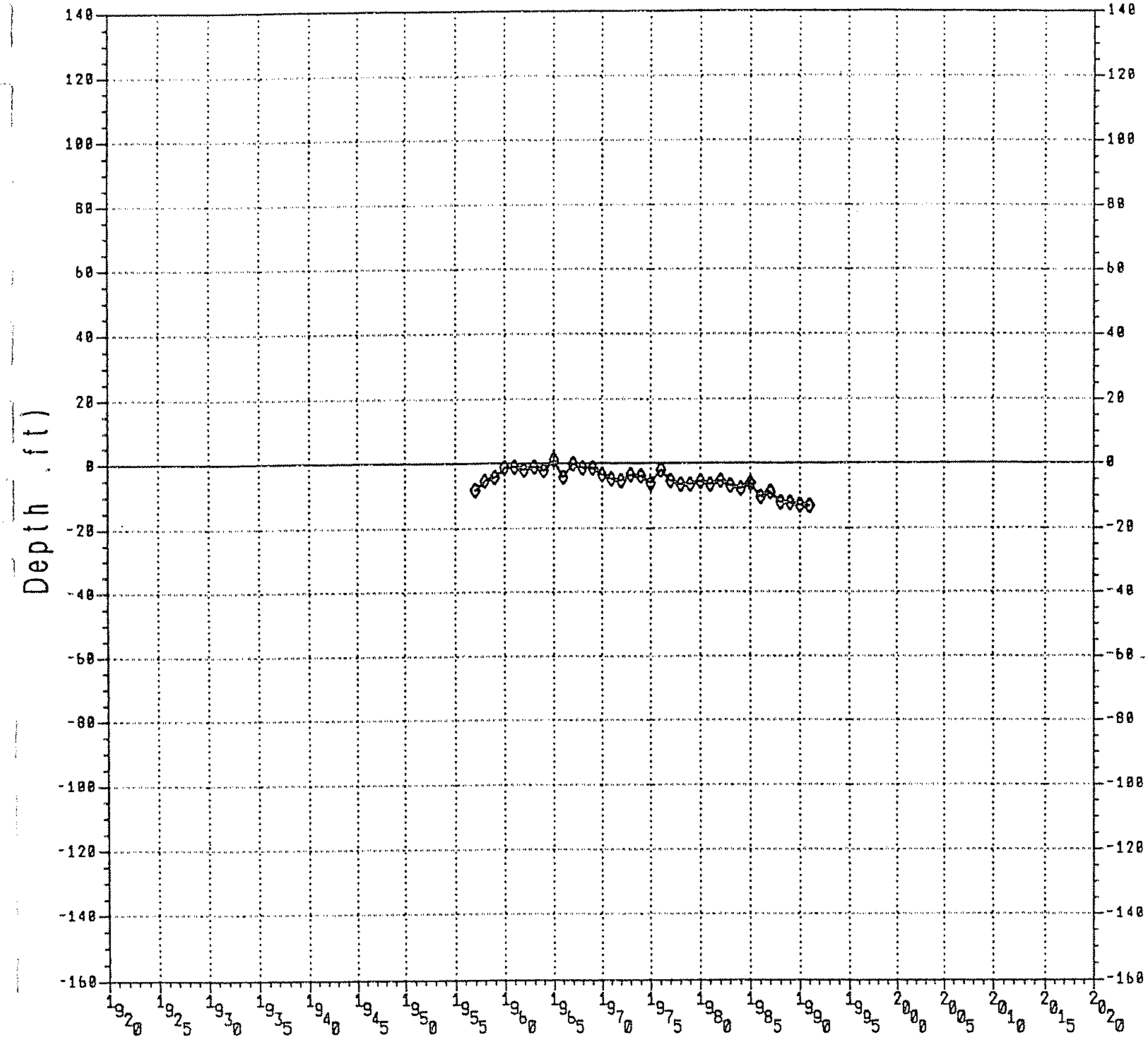
580 - 980

ws: B4 User: RR120186

Coachella Valley Water District

AVERAGE ANNUAL DEPTH from GROUND SURFACE

Well: 06S08E05R02S - CVWD 6858



Basin: INDIO

Area : THERMAL

Perforation Depth (ft)

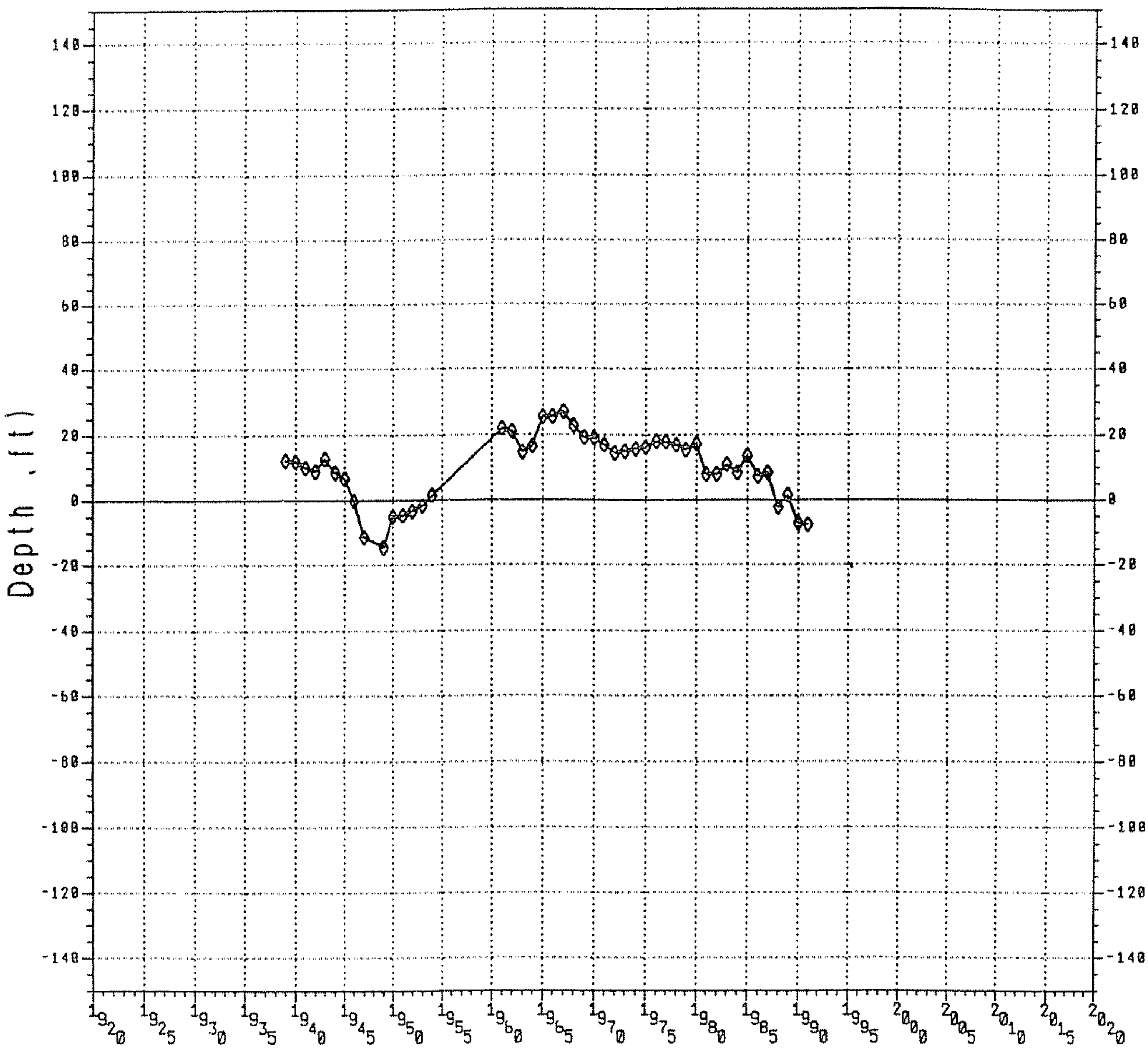
540 - 750

ws: B4 User: RR120186

Coachella Valley Water District

AVERAGE ANNUAL DEPTH from GROUND SURFACE

Well: 06S08E36M01S



Basin: INDIO

Area : THERMAL

Perforation Depth (ft)

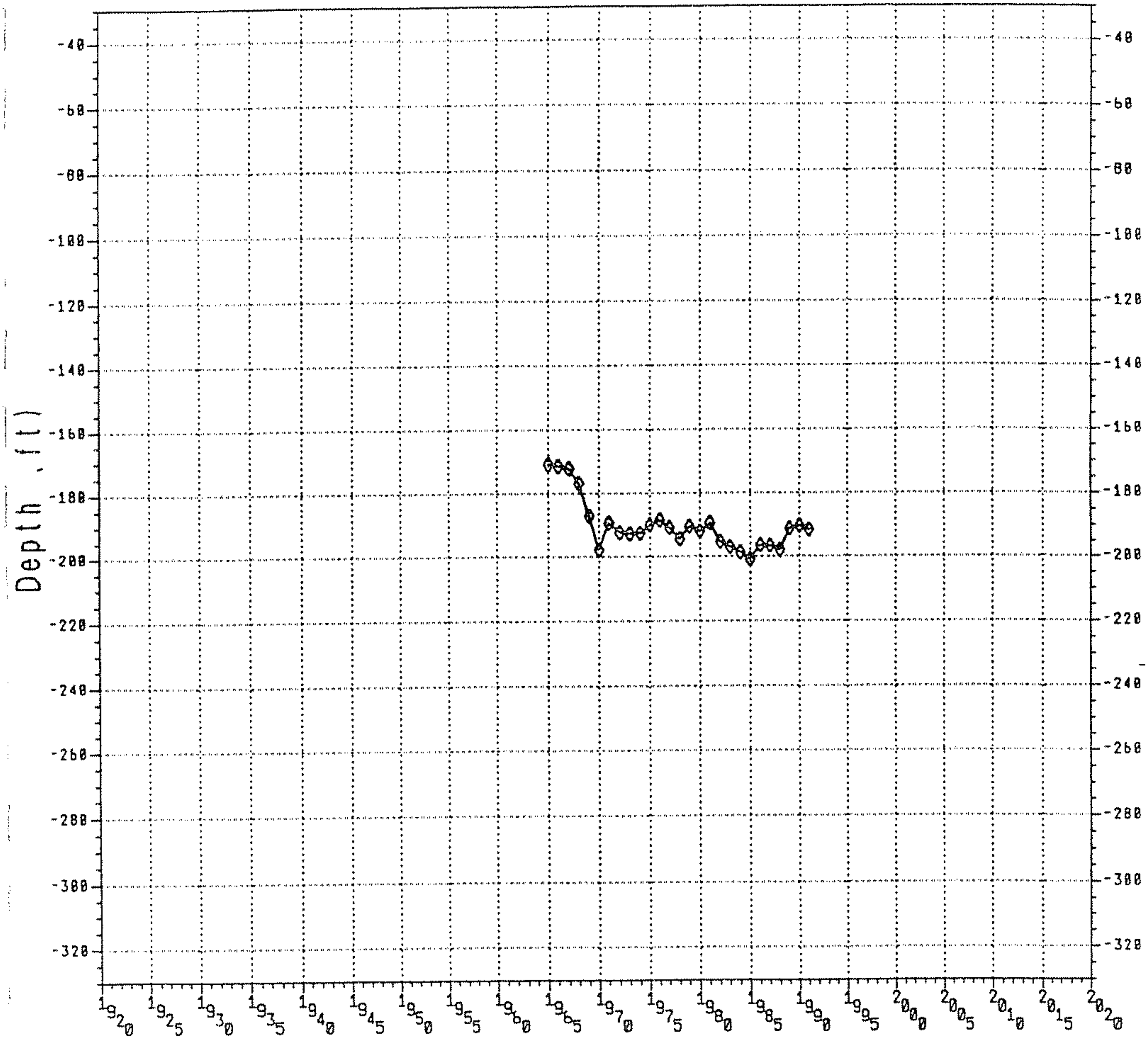
1540 - 1880

ws: B4 User: RR120186

Coachella Valley Water District

AVERAGE ANNUAL DEPTH from GROUND SURFACE

Well: 06S09E33K01S



Basin: INDIO
Area : THERMAL

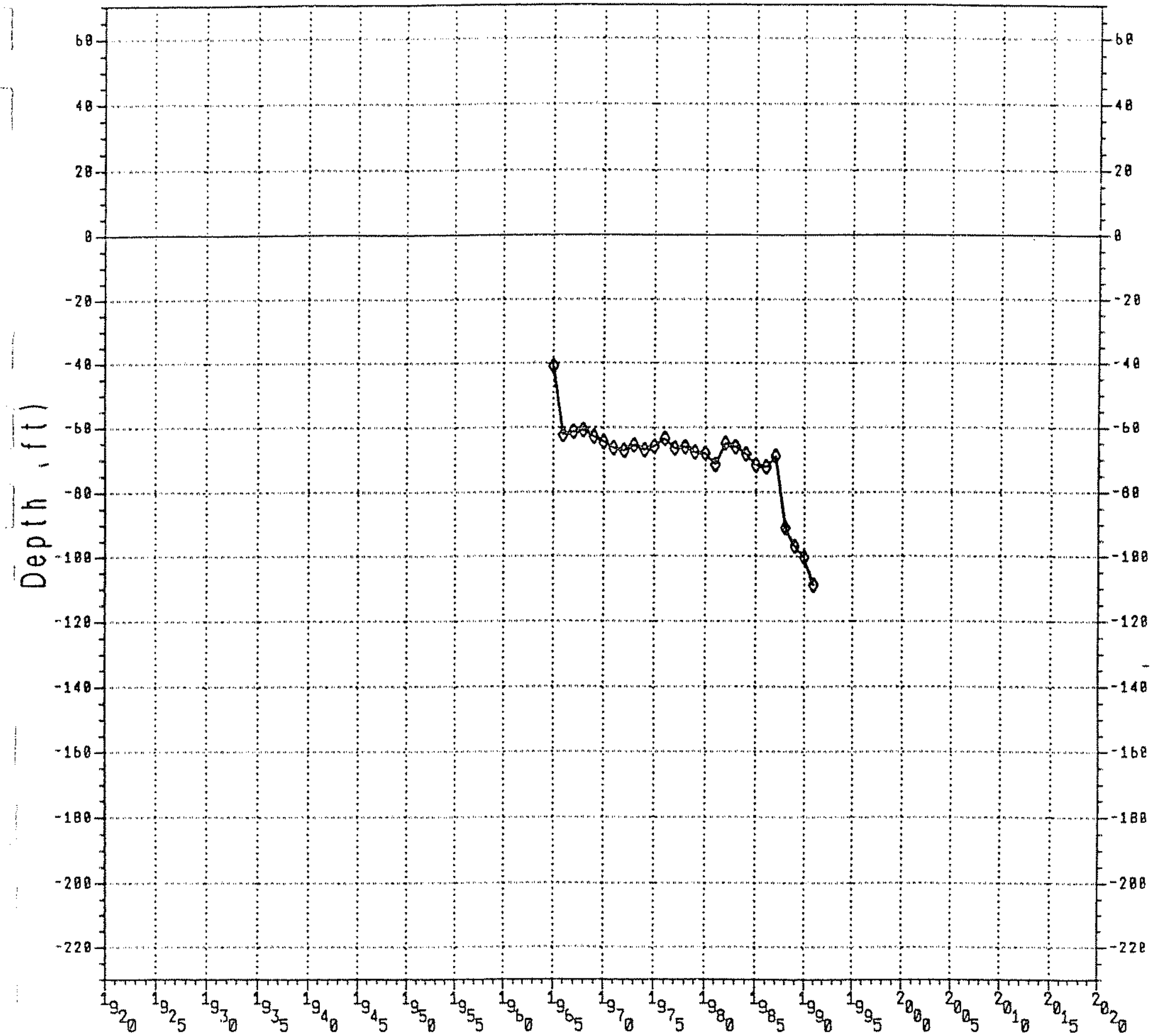
Perforation Depth (ft)
240 - 402

ws: B4 User: RR120186

Coachella Valley Water District

AVERAGE ANNUAL DEPTH from GROUND SURFACE

Well: 06S07E04D02S



Basin: INDIO

Area : THERMAL

Perforation Depth (ft)

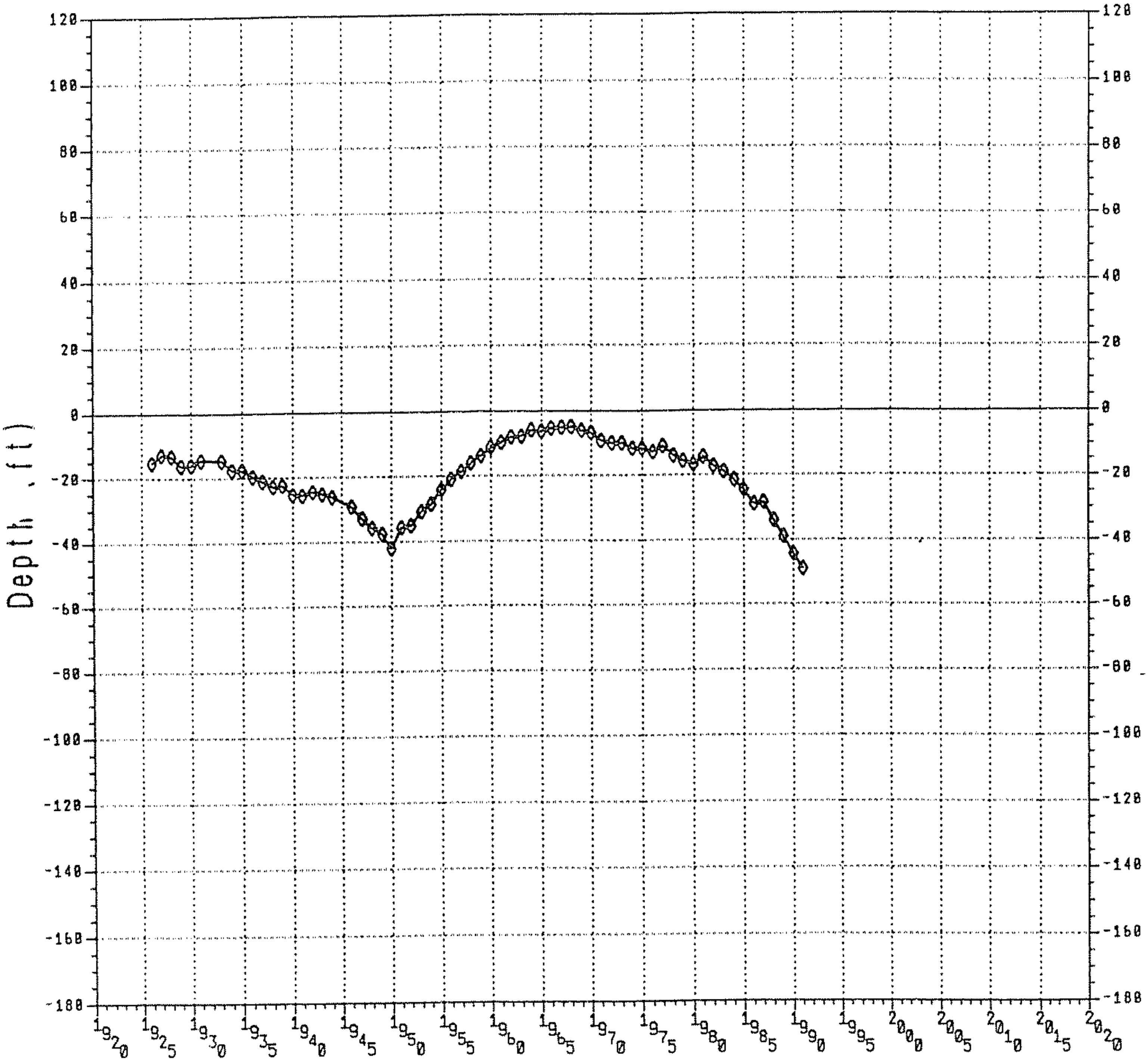
472 - 592

ws: B4 User: RR120186

Coachella Valley Water District

AVERAGE ANNUAL DEPTH from GROUND SURFACE

Well: 06S07E22B01S



Basin: INDIO
Area : THERMAL

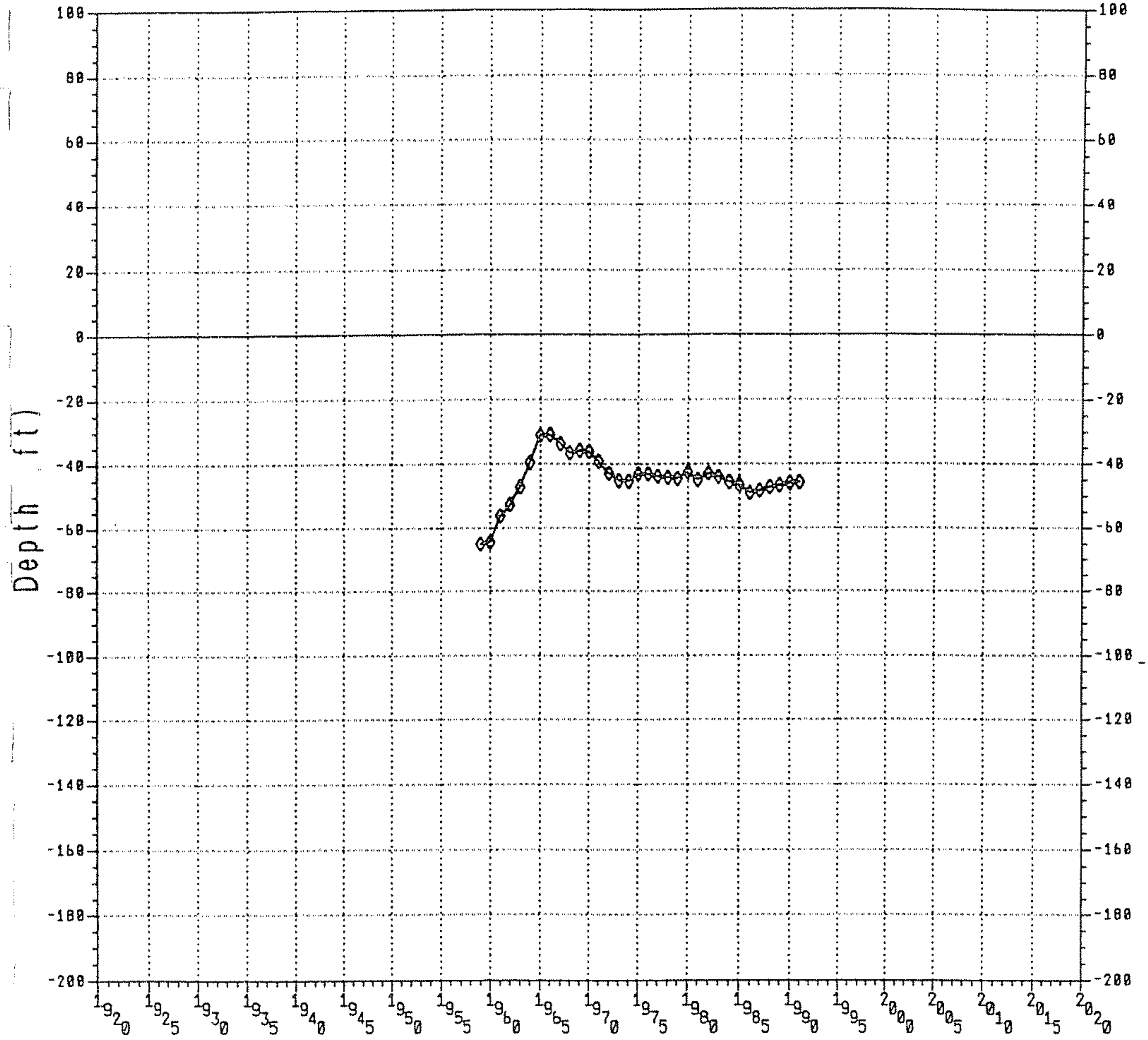
Perforation Depth (ft)
1088 - 1365

ws: B4 User: RR120186

Coachella Valley Water District

AVERAGE ANNUAL DEPTH from GROUND SURFACE

Well: 07S09E13N01S



Basin: INDIO

Area : THERMAL

Perforation Depth (ft)

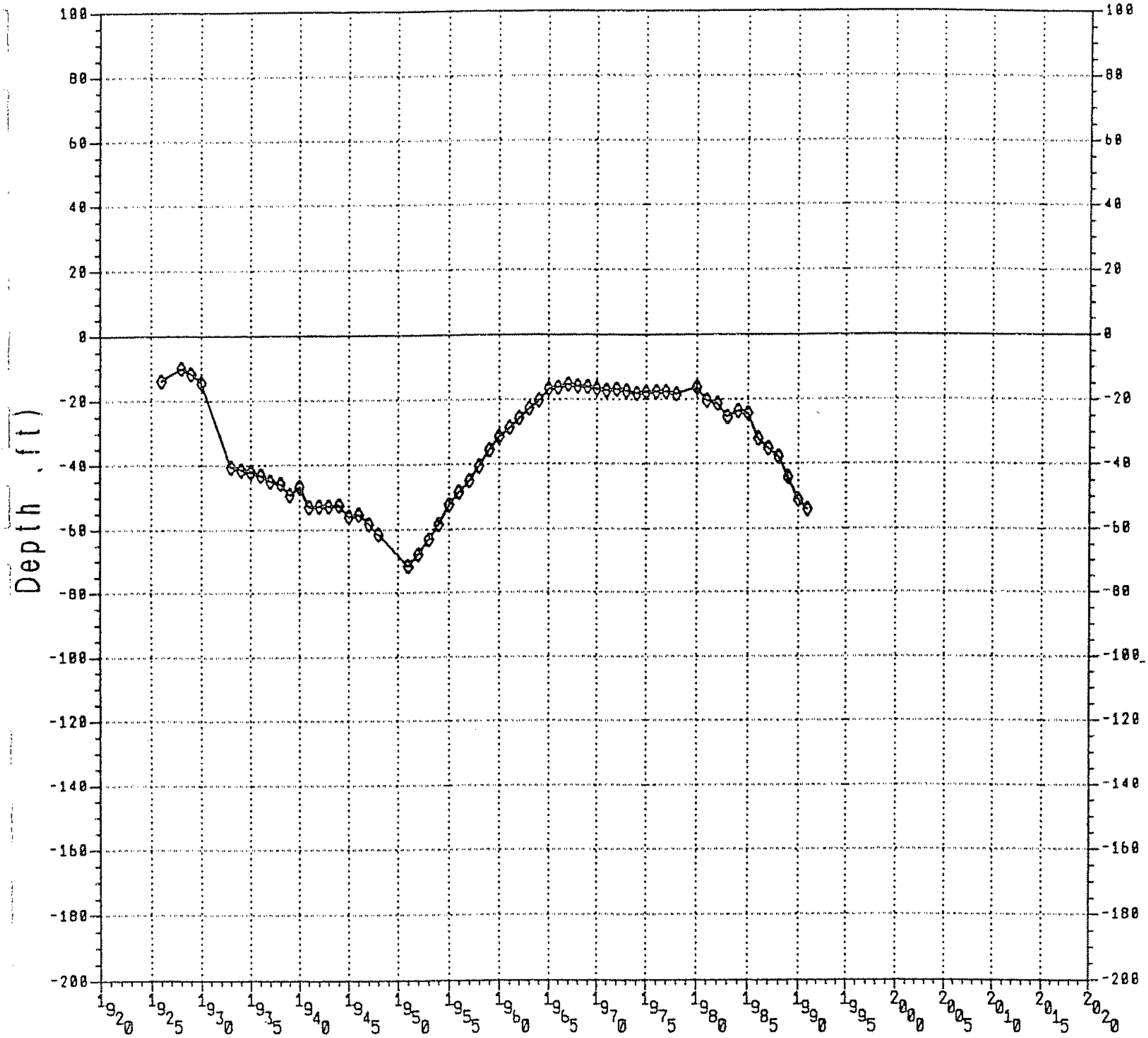
90 - 306

ws: B4 User: RR120186

Coachella Valley Water District

AVERAGE ANNUAL DEPTH from GROUND SURFACE

Well: 07S07E03A01S



Basin: INDIO
Area : OASIS

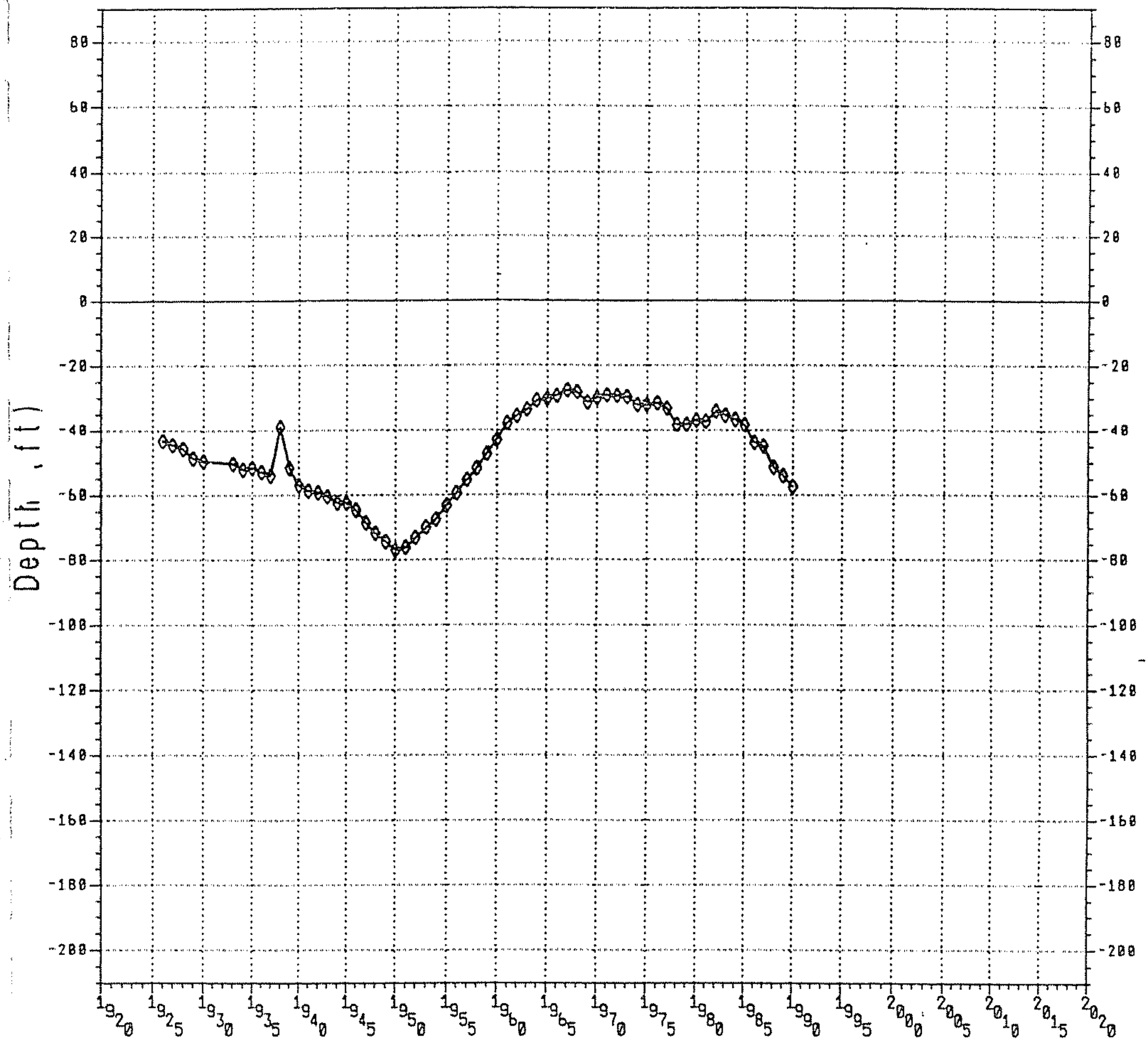
Perforation Depth (ft)
250 - 452

ws: B4 User: RR120186

Coachella Valley Water District

AVERAGE ANNUAL DEPTH from GROUND SURFACE

Well: 07S08E07R01S



Basin: INDIO

Area : THERMAL

Perforation Depth (ft)

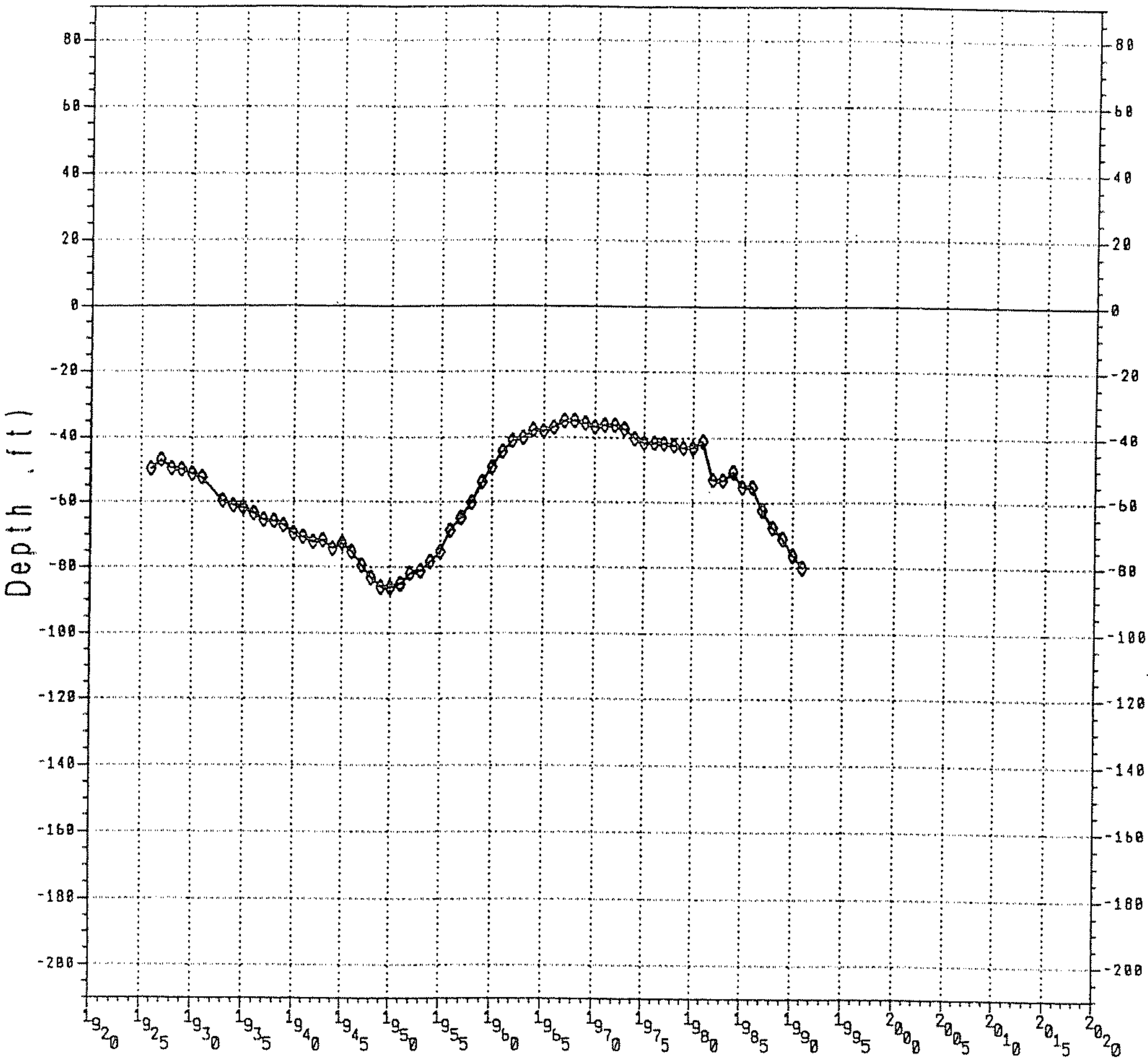
\- 196

ws: B4 User: RR120186

Coachella Valley Water District

AVERAGE ANNUAL DEPTH from GROUND SURFACE

Well: 07S08E34G01S



Basin: INDIO

Area : THERMAL

Perforation Depth (ft)

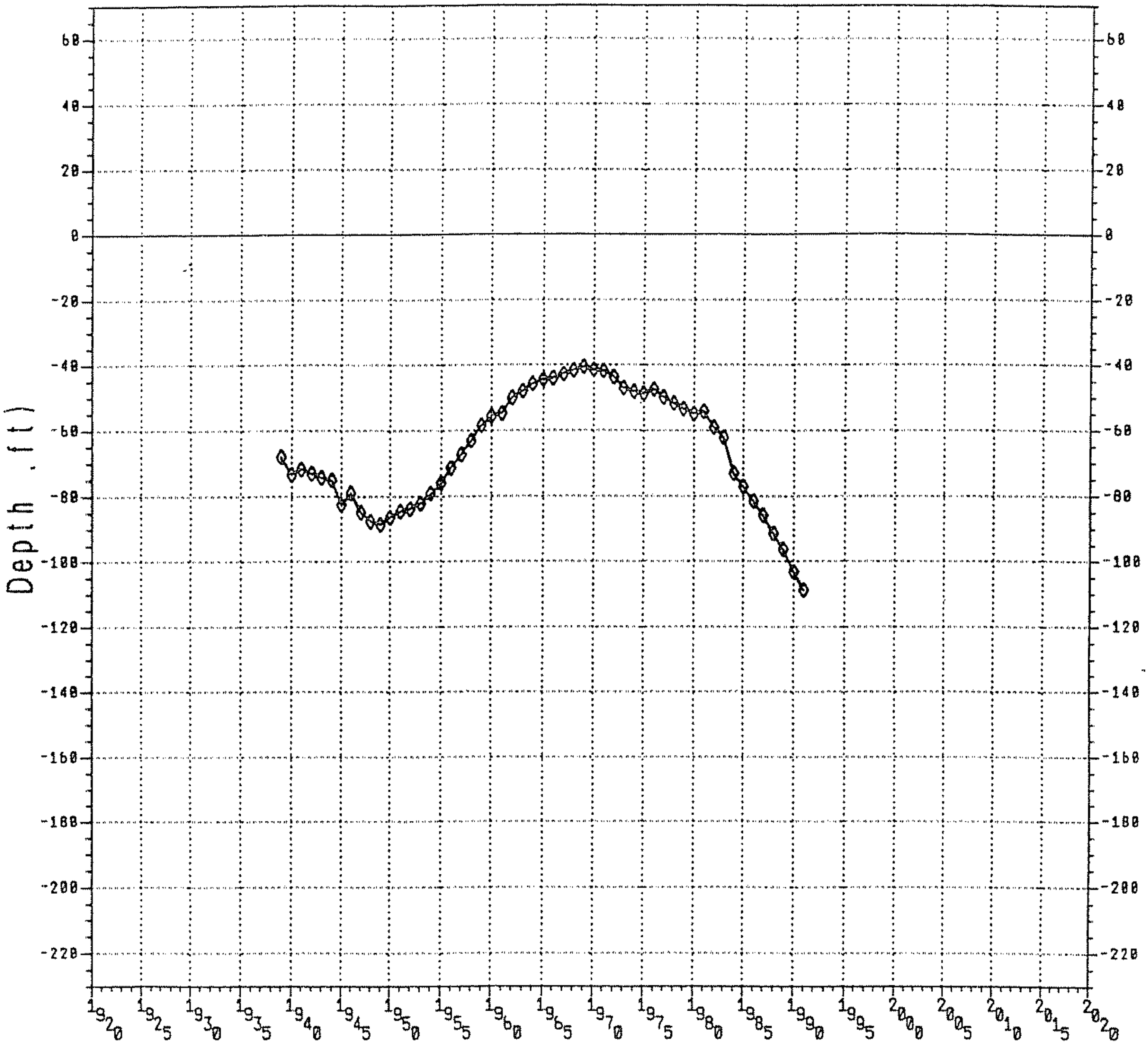
\- 300

ws: B4 User: RR120186

Coachella Valley Water District

AVERAGE ANNUAL DEPTH from GROUND SURFACE

Well: 08S08E24L01S



Basin: INDIO

Area : OASIS

Perforation Depth (ft)

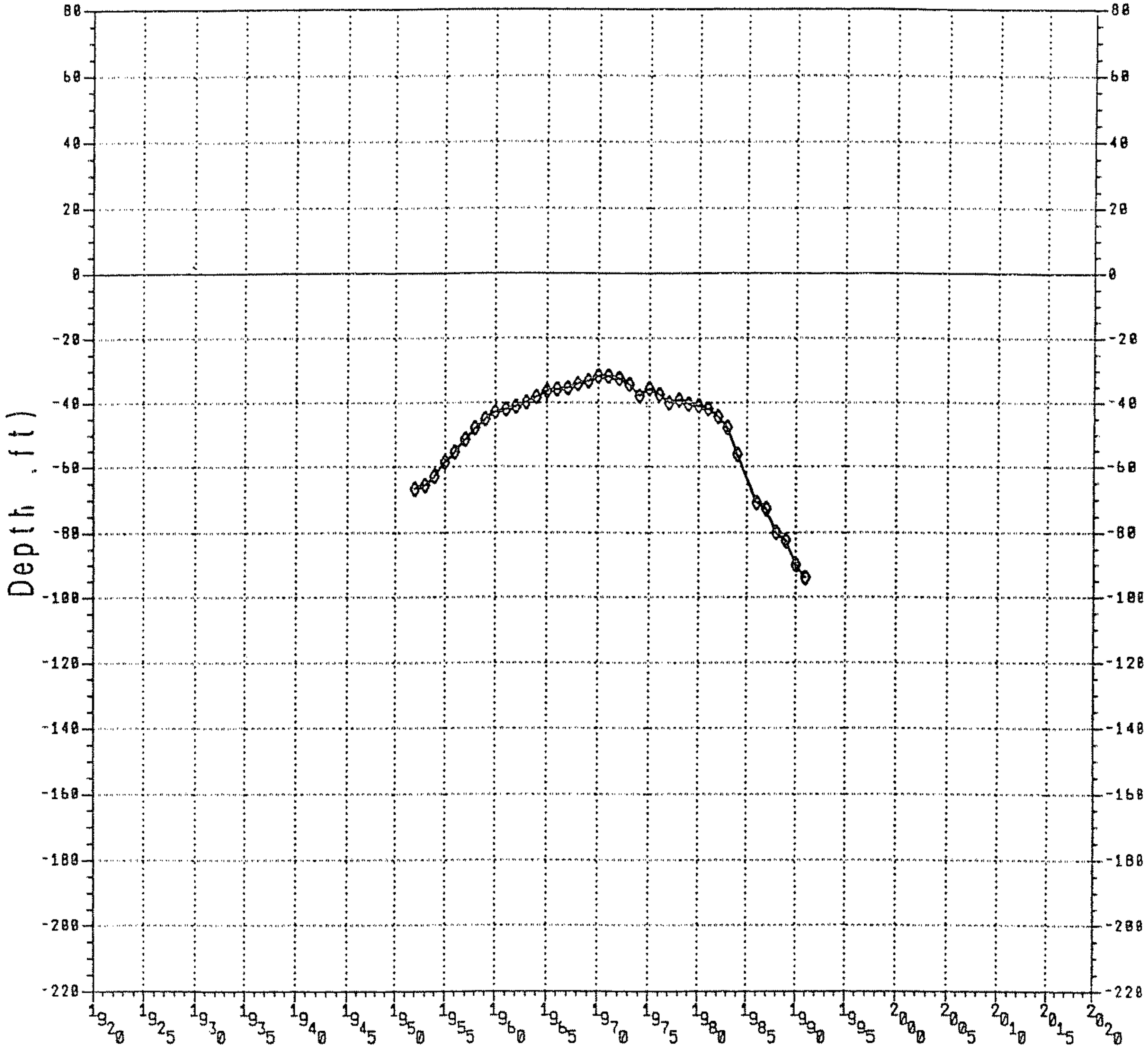
- 550

ws: B4 User: RR120186

Coachella Valley Water District

AVERAGE ANNUAL DEPTH from GROUND SURFACE

Well: 08S09E33N01S



Basin: INDIO
Area : THERMAL

Perforation Depth (ft)
- 356

ws: B4 User: RR120186

APPENDIX E

Irrigation Efficiency Study - USGS Report 91-4142 Data for Coachella Valley

11/20/92

	Well No.	Perforated interval	Land-surface altitude	Altitude of water level (1978)	Altitude of water level (1986)	1978 Depth to Water	1986 Depth to Water
	T4SR7E29E1	330-700	118		-5		123
	T4SR7E29M1	570-680	107		-15		122
	T4SR7E29N2	118-263	103		2		101
	T4SR7E30E3	180-360	161		30		131
	T4SR7E30L1	200-568	150				
	T4SR7E30M1	-	158	30	14	128	144
	T4SR7E30M2	-	148		11		137
	T4SR7E30M6	-	150		13		137
	T4SR7E30P1	148-360	140				
	T4SR7E31Q3	236-356	97	10	-2	87	99
	T4SR7E32G2	280-320	73		-5		78
	T4SR7E32N2	195-462	73	2	-7	71	80
	T4SR7E33N1	100-412	54	4	-2	50	56
	T4SR7E33Q1	240-460	48		-14		62
Average	T4S R7E		113			84	106
	T5SR7E03K1	580-740	44		-51		95
	T5SR7E04A1	147-367	47	-3	-8	50	55
	T5SR7E04C1	520-800	50		-13		63
	T5SR7E04D1	100-370	58	0	-8		66
	T5SR7E04H1	570-840	42		-41		83
	T5SR7E04M1	192-678	51	-3	-10	54	61
	T5SR7E04N1	147-411	51		-16		67
	T5SR7E04Q1	123-363	38		-16		54
	T5SR7E04Q3	240-320	40		-24		64
	T5SR7E05C1	260-400	69		-6		75
	T5SR7E05K1	-	61	-9	-18	70	79
	T5SR7E05R1	230-350	59		-26		85
	T5SR7E06B1	168-180	92	8	2	84	90
	T5SR7E06B3	300-660	90		-8		98
	T5SR7E06H1	400-480	82	-2	-9	84	91
	T5SR7E06M1	195-363	103	11	-3	92	106
	T5SR7E07F1	147-459	102	14	-7	88	109
	T5SR7E07J1	147-363	100	-14		114	
	T5SR7E07P1	144-450	101	3	-10	98	111
	T5SR7E08A2	286-650	55		-26		81
	T5SR7E08G1	-	85	-2	-10	87	95
	T5SR7E08Q1	203-654	54	-13	-16	67	70
	T5SR7E09F1	130-310	39	-16	-17	55	56
	T5SR7E09K1	147-387	33		-22		55
	T5SR7E09L2	147-319	41		-16		57
	T5SR7E10D2	200-530	32		-20		52
	T5SR7E10E1	70-360	28	-18	-22	46	50
	T5SR7E11C1	323-443	29	-12		41	
	T5SR7E12P1	280-400	3	-28		31	
	T5SR7E13D1	580-583	-11	-30		19	
	T5SR7E14J2	232-350	-12	-27		15	
	T5SR7E14K1	264-411	-5	-29		24	
	T5SR7E15Q1	264-464	5	-24		29	
	T5SR7E16C1	147-355	37	-11	-21	48	58
	T5SR7E16K2	200-415	27	-18	-26	45	53
	T5SR7E17E1	459-603	82		-23		105
	T5SR7E17F1	200-720	80				
	T5SR7E17L1	212-600	67		-29		96
	T5SR7E18D1	160-200	129	9	-11	120	140
	T5SR7E18F1	-	112		-8		120
	T5SR7E18M2	168-264	127	4	-18	123	145
	T5SR7E19D1	440-650	140		-18		158
	T5SR7E19H2	460-660	104		-26		130

Irrigation Efficiency Study - USGS Report 91-4142 Data for Coachella Valley

11 20 92

	Well No.	Perforated interval	Land-surface altitude	Altitude of water level (1978)	Altitude of water level (1986)	1978 Depth to Water	1986 Depth to Water
	T5SR7E20P2	150-350	75		-14		89
	T5SR7E21F2	82–614	28		-36		64
	T5SR7E21Q1	-	40		-44		84
	T5SR7E22H2	506-1,100	5	-42	-66	47	71
	T5SR7E23D2	483-882	0		-68		68
	T5SR7E24M4	250-660	-17		-64		47
	T5SR7E25R1	-	-30				
	T5SR7E26E3	515-1,110	5		-78		83
	T5SR7E27B1	236-500	16	-29	-33	45	49
	T5SR7E27L1	516-600	20	-44		64	
	T5SR7E28E1	128-198	46	-20	-31	66	77
	T5SR7E29K1	-	60		-39		99
	T5SR7E30C2	115-235	73	-14	-30	87	103
	T5SR7E30F1	77-84	66	-17		83	
	T5SR7E30F2	-	67	-15		82	
	T5SR7E30J1	500-900	68	-22	-38	90	106
	T5SR7E31N1	110-772	49	-28		77	
	T5SR7E31P1	110-680	55	-19		74	
	T5SR7E33D2	398-518	43	-37		80	
	T5SR7E33F2	400-540	40	-28		68	
	T5SR7E33M1	388-517	40	-35		75	
	T5SR7E36D1	152-756	-21	-45		24	
	T5SR7E36G1	125-345	-32	-45		13	
	T5SR7E36Q1	147-375	-34	-49		15	
Average	T5S R7E		48			63	83
	T5SR8E17N1	278-398	30	-32		62	
	T5SR8E18H1	300-500	-25				
	T5SR8E19H2	402-690	0	-66		66	
	T5SR8E20C2	278-438	-20	-53		33	
	T5SR8E20M1	400-450	-10	-59		49	
	T5SR8E28M1	388-460	-15	-27		12	
	T5SR8E28M2	208-268	-40	14		-54	
	T5SR8E29G1	230-278	-28	0			
	T5SR8E29R1	400-592	-50	29		-79	
	T5SR8E31C3	513-818	-40				
	T5SR8E31J1	240-302	-52	-63		11	
	T5SR8E33D1	521-810	-55				
	T5SR8E34G1	490-789	25	-100		125	
Average	T5S R8E		-22			25	
	T6SR6E01G1	205-296	50	-38		88	
	T6SR6E01Q1	-	55	-28		83	
	T6SR6E12G1	-	90	-38		128	
Average	T6S R8E		65			100	
	T6SR7E01H1	525-595	-45	-70		25	
	T6SR7E01P1	-	-50	-56		6	
	T6SR7E02G1	160-363	-11	-33		22	
	T6SR7E07B1	200-480	50	-128		178	
	T6SR7E09L2	225-300	9	-23		32	
	T6SR7E10G1	100-360	-15	-27		12	
	T6SR7E12E1	120-600	-45	-54		9	
	T6SR7E13M2	146-386	-56	-65		9	
	T6SR7E13M4	480-600	-56	-75		19	
	T6SR7E17R1	-	-5	-57		52	
	T6SR7E22B1	1088-1365	-42	-57		15	
	T6SR7E23D3	380-600	-52	-75		23	

Irrigation Efficiency Study - USGS Report 91-4142 Data for Coachella Valley

11/20/92

	Well No.	Perforated interval	Land-surface altitude	Altitude of water level (1978)	Altitude of water level (1986)	1978 Depth to Water	1986 Depth to Water
	T6SR7E23F1	312-375	-55	-76		21	
Average	T6S R7E		-29			33	
	T6SR8E02D1	292-760	9	-95		104	
	T6SR8E02F1	540-1015	5	-100		105	
	T6SR8E03C1	508-1140	-69	-84		15	
	T6SR8E05P1	216-264	-75	-83		8	
	T6SR8E05R1	206-640	-80	-86		6	
	T6SR8E05R2	540-750	-82	-88	-92	6	10
	T6SR8E05R3	520-650	-80		-99		19
	T6SR8E06G3	200-260	-62	-72		10	
	T6SR8E09K2	468-548	-98	-98		0	
	T6SR8E09Q4	580-680	-102	-98		-4	
	T6SR8E10F1	506-583	-99	-99		0	
	T6SR8E17R1	470-550	-109	-98		-11	
	T6SR8E19D1	1196-1413	-85	-75		-10	
	T6SR8E19D2	450-570	-87	-94		7	
	T6SR8E19R1	-	-105	-75		-30	
	T6SR8E22D2	500-680	-120	-118		-2	
	T6SR8E22K1	500-1030	-128	-134	-123	6	-5
	T6SR8E25P1	478-658	-140	-159	-155	19	15
	T6SR8E27C1	670-1070	-135	-121		-14	
	T6SR8E27N1	312-438	-145	-138		-7	
	T6SR8E32R1	-	-140	-101		-39	
	T6SR8E34C1	447-545	-146	-135	-137	-11	-9
	T6SR8E35J1	514-564	-155	-149	-147	-6	-8
	T6SR8E36M1	1540-1880	-155	-144		-11	
Average	T6S R8E		-99			6	4
	T6SR9E30A1	220-355	-51	-104		53	
	T6SR9E32A1	218-598	20	-185		205	
	T6SR9E32Q1	244-284	-100	-175		75	
	T6SR9E33K1	240-402	40	-169	-157	209	197
Average	T6S R9E		-23			136	197
	T7SR10E27A1	-	34	-18	-16	52	50
	T7SR7E01C1	240-380	-112		-112		0
	T7SR7E03A1	250-452	-72	-90	-104	18	32
Average	T7S R7E		-92			18	16
	T7SR8E02B1	520-575	-161	-155	-157	-6	-4
	T7SR8E03A1	400-500	-159	-149	-154	-10	-5
	T7SR8E07R1	-	-90	-129	-134	39	44
	T7SR8E08N1	300-360	-92		-132		40
	T7SR8E09M1	540-600	-147	-124	-134	-23	-13
	T7SR8E15P1	310-1060	-140				
	T7SR8E17A1	800-1100	-118	-126	-140	8	22
	T7SR8E17F1	265-325	-79	-122	-138	43	59
	T7SR8E17G1	400-750	-78	-122	-136	44	58
	T7SR8E18C1	-	-73	-120	-132	47	59
	T7SR8E18Q1	300-500	2		-146		148
	T7SR8E20B1	210-501	-2	-131	-145	129	143
	T7SR8E20H1	260-486	-22		-134		112
	T7SR8E22K1	446-775	-124	-136	-152	12	28

Irrigation Efficiency Study - USGS Report 91-4142 Data for Coachella Valley

11/20/92

	Well No.	Perforated interval	Land-surface altitude	Altitude of water level (1978)	Altitude of water level (1986)	1978 Depth to Water	1986 Depth to Water
	T7SR8E23Q1	316-416	-181	-165		-16	
	T7SR8E23Q2	365-425	-171	-165	-188	-6	17
	T7SR8E28G1	195-295	-16	-130	-149	114	133
	T7SR8E29D1	360-650	95		-128		223
	T7SR8E29G1	-	80	-129	-146	209	226
	T7SR8E31R1	-	24		-51		75
	T7SR8E33B1	243-522	21	-139	-148	160	169
	T7SR8E33E1	318-702	75	-117	-142	192	217
	T7SR8E33N2	-	75		-157		232
	T7SR8E34G1	-	-92	-134	-150	42	58
	T7SR8E34K1	300-895	-84	-141	-158	57	74
	T7SR8E35K1	-	-161	-140	-144	-21	-17
Average	T7S R8E		-62			53	87
	T7SR9E03D1	320-600	31	-175	-180	206	211
	T7SR9E04C1	300-600	-42	-169	-165	127	123
	T7SR9E04K1	300-600	-65		-174		109
	T7SR9E05M1	460-940	-152	-196	-181	44	29
	T7SR9E07H2	451-566	-188	-183	-188	-5	0
	T7SR9E07J1	410-470	-185		-189		4
	T7SR9E08P1	430-590	-180	-192	-205	12	25
	T7SR9E13N1	90-306	-101	-144	-149	43	48
	T7SR9E16M2	530-590	-186	-199	-213	13	27
	T7SR9E17K1	420-570	-195	-190	-211	-5	16
	T7SR9E22G2	560-620	-173	-201	-203	28	30
	T7SR9E23N1	530-560	-187	-207	-215	20	28
	T7SR9E26G2	336-432	-205	-188	-200	-17	-5
	T7SR9E30M1	-	-213		-203		-10
Average	T7S R9E		-146			42	45
	T8SR8E03B1	485-680	-100	-142	-166	42	66
	T8SR8E03L1	402-618	-59	-139	-163	80	104
	T8SR8E05H1	250-560	9		-236		245
	T8SR8E11A4	300-380	-157	-153	-176	-4	19
	T8SR8E11H1	560-876	-166	-156	-176	-10	10
	T8SR8E15G1	-	55		-77		132
	T8SR8E24A1	800-900	-155	-162		7	
	T8SR8E24A2	-	-154	-162		8	
	T8SR8E24J1	216-312	-148	-169		21	
	T8SR8E24L1	-	-110	-164		54	
Average	T8S R8E		-99			25	96
	T8SR9E30A1	315-595	-152	-168		16	
	T8SR9E31Q1	230-350	-6	-195		189	
	T8SR9E31R1	182-278	-17	-186		169	
	T8SR9E31R2	180-348	-18	-181		163	
	T8SR9E33N1	-	-133	-172		39	
Average	T8S R9E		-65			115	
Average Entire Database						62	95
Average of Fringe Area						78	115

APPENDIX F

SHEET 1/2

TOTAL DYNAMIC HEAD CALCULATION

12/16/92 S:

ASSUMPTIONS:

- STATIC LIFT = 100 FT (COMMAND AREA) 120 FT (OUTSIDE)
- SPECIFIC YEILD = 40 GPM / FT
- AVE PUMP Q = 800 GPM
- COLUMN DIA = 8" (C = 120)
- PUMP SET DEPTH = 200 FT
- DISHARGE P = 10 FT

CALCS:

1. DRAWDOWN = Q / SPECIFIC YEILD

   = 800 GPM / 40 GPM/FT = 20 FT ✓

2. MINOR LOSSES

$$Hf = Hf(\text{VALVES}) + Hf(\text{ELBOW}) + Hf(\text{PIPE}) + Hf(\text{OTHER})$$

$$Hf(\text{PIPE}) = \left[10.50\ (Q/C)^{1.852} / D^{4.87}\right] \times L$$

$$= \left[10.50 \times (800/120)^{1.852} / 8^{4.87}\right] \times 240\text{ FT}$$

$$= 3.38\text{ FT}$$ ✓

EQUIVELENT L → Hf (VALVES) & ELBOW = 4.40 + 53.0 + 22.0 = 79.4 FT

(FROM BYRON JACKSON PG 2-520-25 PUMP MANUAL)

$$= 10.50 \times (800/120)^{1.852} / 8^{4.87} \times 79.4\text{ FT}$$

$$= 1.12\text{ FT}$$ ✓

Hf (OTHER) = 5.0 FT ASSUMED ✓

TOTAL MINOR LOSSES = 3.38 + 1.12 + 5.0 = 9.5' (USE 10.0')

3. TOTAL DYNAMIC HEAD CALCULATION 12/16/92 SS

TDH =
STATIC LIFT
+ DRAWDOWN
+ MINOR LOSSES
+ DISCHARGE PRESSURE

TDH (COMMAND AREA) = 100' + 20' + 10' + 10' = 140 FT

TDH (OUTSIDE CVWD) = 120' + 20' + 10' + 10' = 160 FT

GENERAL ENGINEERING DATA

FRICTION LOSS THROUGH PIPE FITTINGS AND VALVES

SIZE OF PIPE INCHES	GATE VALVE WIDE OPEN	GATE VALVE 1/4 CLOSED	GATE VALVE 1/2 CLOSED	GATE VALVE 3/4 CLOSED	GLOBE VALVE WIDE OPEN	ANGLE VALVE WIDE OPEN	CHECK VALVE WIDE OPEN	ORDINARY ENTRANCE TO PIPE LINES	STANDARD 90 DEGREE ELBOW	MEDIUM SWEEP 90 DEGREE ELBOW	LONG SWEEP 90 DEGREE ELBOW
STRAIGHT PIPE IN FEET (EQUIVALENT LENGTH)											
1/8"	.14	.85	5.	19	9	5	2.	.46	.74	.65	.50
1/4"	.21	1.25	7.	26	12	6	3.	.60	1.0	.86	.70
3/8"	.27	1.80	9.	36	16	8	4.	.75	1.4	1.15	.90
1/2"	.33	2.10	12.	44	18	9	5.	.90	1.6	1.50	1.10
3/4"	.46	2.9	14.	59	23	12	6.	1.4	2.3	2.0	1.5
1"	.61	3.4	18.	70	29	15	7.	1.6	2.7	2.5	2.0
1-1/4"	.79	4.8	24.	96	38	20	9.	2.5	3.6	3.5	2.5
1-1/2"	.93	5.6	28.	116	46	23	11.	3.0	4.5	4.0	2.9
2"	1.21	7.0	36.	146	58	29	15.	3.5	5.4	5.0	3.6
2-1/2"	1.39	8.4	41.	172	69	35	17.	4.0	6.5	6.0	4.4
3"	1.69	10.0	52.	213	86	43	21.	5.0	8.5	7.0	5.5
3-1/2"	2.10	12.5	60.	246	100	52	24.	5.5	10.0	8.5	6.3
4"	2.40	14.0	70.	285	116	57	27.	6.5	12.	9.5	7.2
4-1/2"	2.50	15.6	77.	317	124	64	30.	7.5	14.	11.	8.4
5"	2.70	17.5	84.	355	145	70	34.	8.5	16.	13.	9.5
6"	3.40	20.0	105	425	175	86	39.	9.5	17.	15.	11.2
7"	4.10	22.2	122	476	194	99	46.	12.	19.	17.	13.1
8"	4.40	26.5	136	555	225	115	53.	14.	22.	19.	15.3
9"	5.20	29.0	153	625	254	126	59.	15.	24.	21.	16.3
10"	5.70	33.5	172	703	285	141	65.	16.	27.	23.	18.2
12"	6.80	40.6	196	815	336	166	78.	18.	33.	27.	20.2
14"	8.20	48.5	233	978	395	195	92.	21.	37.	31.	23.3
16"	9.10	53.0	274	1110	435	220	106.	26.	43.	36.	27.5
18"	10.00	60.5	305	1305	510	253	120.	29.	47.	42.	31.4
20"	12.00	67.6	332	1410	560	276	136.	31.	53.	46.	34.5
22"	13.20	73.5	373	1500	610	305	145.	34.	59.	50.	38.6
24"	14.00	80.0	405	1608	680	338	154.	36.	64.	55.	41.5
30"	17.30	100.	510	2000	860	425	195.	45.	82.	70.	51.4
36"	20.00	126.	608	2540	1000	500	243.	56.	96.	80.	61.5
42"	23.50	144.	706	2820	1220	594	285.	67.	116.	100.	72.3
48"	26.00	159.	810	3350	1430	683	320.	76.	132.	115.	83.5
54"	29.40	176.	905	3760	1640	775	364.	80.	146.	136.	94.6

NOTE: 1/8 to 12 inch are standard pipe sizes; 14 to 54 inch are inside diameter pipes.

APPENDIX G

State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES
San Joaquin District

ESTIMATED CROP EVAPOTRANSPIRATION IN THE COACHELLA VALLEY, CALIFORNIA 1/

February 1981

This report presents estimated monthly and growing season total evapotranspiration (ET) rates for 18 crops grown in the Coachella Valley. Based upon a recent land use survey (8), the aggregated acreage for those 18 crops represents over 90 percent of the total crop acreage in the Valley. 2/

A method for estimating effective precipitation is suggested and effective precipitation for each crop for the "average" rainfall year was calculated. Methods used for estimating crop ET and effective precipitation are described below.

Locally Measured Crop ET

ET rates for two locally important crops, date palms and vineyard, have been measured in the Coachella Valley (2 and 11). An annual ET rate of 72.4 inches for Deglet Noor dates has been reported (2). That ET rate was based upon soil sampling of a field plot during 1936-38. More recently, an annual ET rate for Khadrawy palm trees was determined to be 63 inches (11). That ET estimate was based upon gravimetric sampling of a field plot in the early 1950's. For this report, the annual ET rate for date palms was estimated as 68 inches -- the average of results from the two field plots (see Tables 1 and 2).

Monthly ET rates determined from gravimetric sampling of Thompson seedless grapes in the Coachella Valley have been published (2 and 11). For the April through October growing season, ET amounted to 39.3 inches and total annual ET was 43.6 inches. For this report, growing season ET (based upon that field study) was estimated as 39.9 inches (Tables 1 and 2).

Measured Crop ET for Other Desert Areas

Reliable crop ET rates have been determined for several field crops in the Imperial Valley. Robert D. Le Mert, Carl F. Ehlig, and Burl D. Meeks, with the

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1/ ET rates estimated by N. A. MacGillivray, Department of Water Resources, San Joaquin District, Water Utilization Section, January 12, 1981.

2/ Numbers in parentheses refer to references listed.

TABLE 1

SUMMARY OF ESTIMATED GROWING SEASON EVAPOTRANSPIRATION AND EFFECTIVE PRECIPITATION FOR SEVERAL CROPS IN THE COACHELLA VALLEY

Crop	Assumed Growing Season	Estimated Growing Season ET (inches)	Estimated Effective Precipitation (inches) 1/
Field Crops			
Alfalfa	1/01 - 12/31	80.6	1.4
Cotton	4/15 - 10/15	40.9	0.8
Forage Sorghum	4/15 - 11/15	50.5	0.6
Grain Sorghum	7/01 - 10/31	24.4	0.6
Grain Sorghum	4/01 - 7/31	30.2	0.1
Onions	11/01 - 5/15	26.0	1.4
Pasture	1/01 - 12/31	81.1	2.8
Truck Crops			
Asparagus	3/01 - 12/15	65.4	1.5
Carrots	8/15 - 12/15	16.3	0.8
Carrots	10/15 - 3/15	14.9	1.5
Carrots	1/01 - 5/15	23.9	0.7
Green Onions	9/15 - 1/31	13.6	1.4
Lettuce	9/15 - 12/31	12.6	0.9
Melons	2/01 - 6/30	34.3	0.3
Peppers	11/01 - 5/31	33.5	1.4
Sweet Corn	8/01 - 12/01	21.1	0.8
Sweet Corn	1/15 - 5/15	24.2	0.6
Sweet Corn	2/15 - 6/15	31.7	0.3
Tomatoes	1/15 - 5/15	22.1	0.5
Watermelons	1/01 - 5/31	25.4	0.7
Trees and Vines			
Citrus	1/01 - 12/31	46.7	2.8
Dates	1/01 - 12/31	68.0	2.8
Vineyard	3/01 - 10/31	39.9	1.3

1/ Based upon average of long-term precipitation at Indio Date Garden, Mecca Fire Station, and Thermal FAA - AP (15).

TABLE 2

SUMMARY OF ESTIMATED MONTHLY EVAPOTRANSPIRATION FOR TREES AND VINEYARDS IN THE COACHELLA VALLEY (inches)

Month	Citrus	Dates	Vineyard
Jan	1.3	2.7	0.4
Feb	1.8	3.2	0.5
Mar	3.2	4.3	1.5
Apr	4.2	5.8	3.4
May	5.5	7.4	6.0
Jun	6.8	7.8	8.0
Jul	6.6	8.5	7.7
Aug	5.9	9.4	6.4
Sep	4.8	8.1	4.4
Oct	3.4	5.1	2.5
Nov	1.9	3.4	1.2
Dec	1.3	2.3	0.7
Total	46.7	68.0	42.7

U. S. Department of Agriculture, Imperial Valley Conservation Research Center at Brawley, have measured the ET rates for alfalfa,.barley, cotton, sugar beets, and wheat. Two of those crops, alfalfa and cotton, are important in the Coachella Valley. Together they amount to over 16 percent of the total cropped acres (8). Estimates of potential ET in the Coachella Valley calculated for this report are very similar to potential ET in the Imperial Valley. Therefore, monthly ET for alfalfa and cotton measured in the Imperial Valley were, with very slight adjustments for differences in growing season, used for the Coachella Valley (Tables 1 and 3).

L. J. Erie of the U. S. Department of Agriculture, Agricultural Research Service, and his colleagues, working in Arizona, have measured ET rates for a large number of crops (10). Comparison of ET rates for crops measured in both Arizona and the Imperial Valley have shown reasonable agreement. Therefore, ET determined for several crops in Arizona was either used for the Coachella Valley or used as a check on ET rates estimated by other methods (see Tables 1, 2, 3, and 4).

Estimated Crop ET

There were no ET measurements made in desert climates for many of the crops grown in the Coachella Valley, therefore ET for those crops was estimated from climatological data. Generally, regional ET estimates made by the Department of Water Resources are based upon either observed atmometer evaporation or observed evaporation from a U. S. Weather Bureau Class 'A' pan located in a large, well-managed irrigated pasture (3). Neither suitable pan nor atmometer evaporation data were available in the Coachella Valley (5 and 14).

The Food and Agricultural Organization (FAO) of the United Nations has recently published a paper that describes a method for estimating crop ET from measured or estimated ET of a grass reference crop (9). The grass crop must have a smooth surface, be sufficiently large in size to minimize local advective effects, provide 100 percent ground cover, and be adequately supplied with soil moisture to prevent plant moisture stress. ET of grass meeting those criteria is defined as potential ET (PET). The FAO publication also describes methods for estimating PET from climatological data.

Table 5 shows five estimates of PET for the Coachella Valley made by various methods. Annual total PET estimates were within 8 percent or less of the average for the five methods. The five estimates of monthly PET were averaged and values from a smoothed curve of those averages were selected to characterize PET in the Coachella Valley. PET for the Coachella Valley thus determined is considered to be in good agreement with estimates of PET for the Imperial Valley and for the southeastern California desert (Table 5).

Local climatological data used in making the PET estimates are shown in Table 6.

Monthly ET for a number of important crops in the Coachella Valley were estimated from PET and crop coefficients shown in the FAO report (9).

TABLE 3

SUMMARY OF ESTIMATED MONTHLY EVAPOTRANSPIRATION
FOR MAJOR FIELD CROPS IN THE COACHELLA VALLEY
(inches)

Month	Alfalfa	Cotton	Grain Sorghum		Dry Onions	Forage Sorghum	Irrigated Pasture
			Spring	Summer			
Jan	2.6				2.5		2.6
Feb	3.0				3.5		3.5
Mar	6.2				5.9		5.9
Apr	7.0	3.0	2.7		7.0	2.3	7.6
May	9.3	4.9	9.0		4.0	7.5	10.0
Jun	10.9	6.0	12.5			11.4	11.4
Jul	12.2	7.8	6.0	3.3		5.0	11.0
Aug	8.8	8.1		7.8		10.8	9.8
Sep	9.2	6.9		8.8		4.0	8.0
Oct	5.8	2.9		4.5		5.6	5.6
Nov	3.7	1.3			1.4	3.9	3.4
Dec	1.9				1.7		2.3
Total	80.6	40.9	30.2	24.4	26.0	50.5	81.1

TABLE 4

SUMMARY OF ESTIMATED MONTHLY EVAPOTRANSPIRATION
FOR MAJOR TRUCK CROPS IN THE COACHELLA VALLEY
(inches)

Month	Asparagus	Carrots			Corn - Market			Lettuce	Melons 1/	Green Onions	Peppers	Tomatoes Market	Watermelons
		Summer	Fall	Winter	Summer	Winter	Late Winter						
Jan	0.8		2.9	1.7		0.8				2.6	2.6	0.8	1.3
Feb	1.0		3.8	3.2		2.8	1.0		2.3		3.7	2.4	2.4
Mar	1.8		2.7	6.5		6.5	4.7		4.7		6.2	6.2	5.6
Apr	4.2			8.0		8.7	8.4		7.6		8.0	8.7	7.6
May	8.6			4.5		5.4	11.5		10.0		9.5	4.0	8.5
Jun	10.3						6.1		9.7				
Jul	11.0												
Aug	9.8	3.4			3.9								
Sep	8.0	5.2			7.2			2.8		1.7			
Oct	5.6	5.0	1.3		6.4			4.5		3.6			
Nov	3.1	2.7	2.0		3.6			3.1		3.4	1.8		
Dec	1.2		2.2					2.2		2.3	1.7		
Total	65.4	16.3	14.9	23.9	21.1	24.2	31.7	12.6	34.3	13.6	33.5	22.1	25.4

1/ Mostly honeydews and casabas.

TABLE 5

ESTIMATED NORMAL POTENTIAL EVAPOTRANSPIRATION
IN THE COACHELLA VALLEY
(inches per month)

Month	Blaney-Criddle 1/	Modified Blaney-Criddle 2/	Radiation 3/	Radiation 4/	USBR Jensen-Haise 5/	Average 6/	Estimated Coachella Valley 7/	Bulletin 113-3 SE Desert 8/	Estimated Imperial Valley 9/
Jan	2.9	2.8	2.7	3.3	1.9	2.7	2.6	2.7	2.6
Feb	3.8	3.5	3.3	3.9	2.6	3.4	3.5	3.6	3.4
Mar	5.8	6.8	5.9	6.9	4.8	6.0	5.9	5.9	5.8
Apr	7.6	8.5	8.0	9.0	7.4	8.1	7.6	7.6	7.6
May	10.0	10.8	9.5	10.8	8.7	10.0	10.0	10.1	9.8
Jun	10.8	12.0	10.2	11.5	10.5	11.0	11.4	11.4	11.3
Jul	12.1	10.9	9.1	9.7	11.4	10.6	11.0	11.6	10.9
Aug	10.7	10.0	8.1	9.0	10.7	9.7	9.8	9.6	9.7
Sep	8.1	8.1	6.8	7.4	8.3	7.7	8.0	8.5	7.9
Oct	5.9	5.8	5.1	5.7	5.5	5.6	5.6	6.3	5.6
Nov	3.5	3.7	3.1	3.7	2.8	3.4	3.4	3.5	3.4
Dec	2.5	2.7	2.4	3.0	1.7	2.5	2.3	2.0	2.2
Total	83.7	85.6	74.2	83.9	76.3	80.7	81.1	82.8	80.2

1/ Calculated by Blaney-Criddle method using Coachella Valley temperature data and monthly crop coefficients (K's) determined from L. Erie's observed ET-alfalfa in Arizona. Smoothed to adjust for variations in mowing and regrowth (1 and 10).

2/ Blaney-Criddle method modified for effects of humidity, wind, and sunshine hours as described in UN-FAO No. 24 (9).

3/ Calculated from radiation observed at Coachella ISE using method described in UN-FAO No. 24 (9).

4/ Calculated using radiation method described in UN-FAO No. 24 with radiation from four southeast desert locations (6 and 9).

5/ From Table 16, page 93, "Use of Water on Federal Irrigation Projects". U. S. Bureau of Reclamation (now Water and Power Resources Service), September 1961 (13). (ET-grass calculated using Jensen-Haise method).

6/ Average of five estimates of PET.

7/ Average of five estimates of PET with monthly values smoothed.

8/ Estimate of PET for Southern California desert. From Table 6, DWR Bulletin 113-3 (3).

9/ From Table 1, "Estimated Crop Evapotranspiration in the Imperial Valley, California" (7).

TABLE 6

CLIMATOLOGICAL DATA USED FOR ESTIMATING POTENTIAL EVAPOTRANSPIRATION IN THE COACHELLA VALLEY

Station	Air Temp.	Wind Movement	Humi-dity	Solar Radi-ation	Daytime Cloud Cover, %	Preci-pitation
Brawley 2SW	-	-	-	5/	-	-
Coachella Valley CWD	-	2/	4/	6/	4/	-
El Centro 7NW	-	-	-	7/	-	-
Indio - Date Garden	1/	3/	-	-	-	9/
Mecca Fire Station	1/	-	-	-	-	9/
Palm Springs	1/	-	-	-	-	-
Salton Sea	-	-	-	8/	-	-
Thermal FAA - AP	-	-	4/	-	4/	9/

1/ Long-term average mean monthly air temperatures, Table 1, "Climatological Data - Annual Summary - 1979", Volume 83, No. 13, NWS (15).

2/ Unpublished monthly wind record, January 1973 - June 1974.

3/ Monthly wind record, January 1966 - December 1975. NWS "Climatological Data, various volumes (15). WPRS (formerly USBR) reports anemometer was at approximately 75-foot height until late 1966 when it was lowered to 16 feet above ground (13).

4/ Humidity and cloud cover record from Coachella Valley CWD 1966-1967; humidity from Thermal 1968 and 1969; cloud cover from Thermal 1968. Appendix A, "Use of Water on Federal Irrigation Projects". USBR, September 1971 (13).

5/ Ten-year average, January 1962 - December 1971. Table 3, DWR Bulletin 187 (6).

6/ Average January 1966 - July 1973. Table 3, DWR Bulletin 187 (6).

7/ Average January 1963 - December 1976. Table 3, DWR Bulletin 187 (6).

8/ Average March 1967 - December 1968. Table 3, DWR Bulletin 187 (6).

9/ Long-term average. Table 2, "Climatological Data - Annual Summary - 1979", Volume 83, No. 13, NWS (15).

Crop growing seasons were obtained from a University of California publication (12) and from a representative of the Riverside County Agricultural Commissioner's Office.1/

Crop-growing seasons used are shown in Table 1. Monthly estimates of crop ET are listed in Tables 2, 3, and 4. Growing-season total ET is shown for the 18 selected crops in Table 1.

Effective Precipitation

Records for three locations in the Valley (see Table 6) were used to determine average precipitation (15). The long-term average annual rainfall for the agricultural area of the Valley is 2.8 inches. The precipitation record for Palm Springs was not used as that location is not within the major agricultural area of the Valley (4).

Although the rainfall is sparse and unpredictable as to time of occurrence, there is some contribution toward meeting the ET demand of many crops. For this report, only rainfall occurring during crop-growing seasons is considered to be effective; that is, there is no appreciable carryover of precipitation as stored soil moisture from rains falling before the crops are planted. For the rain falling during the crop-growing seasons, 100 percent was considered effective for crops at full ground cover. For the period between planting and the attainment of full cover, 50 percent of the rain was considered to be effective. The estimated amounts of effective precipitation are shown in Table 1.

Both crop ET and effective precipitation are needed to calculate crop irrigation requirements. These are shown in Table 1. Also needed are estimates of leaching requirements and irrigation application efficiencies. These last two items have not been included in this report.

1/ Telephone conversation with Mr. Ruben Arias, Riverside County Agricultural Commissioner's Office, October 10, 1979.

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APPENDIX H

Salinity, Drainage, and ET Issues in the Imperial Valley

A Partial Status Report of Current Opinions
and Future Research Needs

Made to
Imperial Irrigation District

by

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Foreward

The answers to two technical on-farm irrigation questions are important for IID (a) in determining the need for reasonable and beneficial use of water, and (b) for estimates of how much water may be available for future water transfer. The two questions are:

1. How much water is needed for salt control?
2. What are the unstressed evapotranspiration (ET) requirements of crops?

This report does not answer those questions satisfactorily, because there are many gray areas in current knowledge. However, it does bring many gray areas to light and does conclude with some estimates regarding salt control needs.

This report should be considered as a basis for further dialog. The conclusions are based upon the author's experience, plus interpretation of literature and limited field data.

When reports such as this are read by interested parties, new facts and interpretations come to light. It is hoped that those revelations can be brought forward in a positive and constructive forum to achieve a consensus and arrive at a better understanding of these technical issues.

Introduction

IID is currently faced with challenges and opportunities regarding improved on-farm water management and water conservation. Of particular concern is the question of "How much water is needed for reasonable and beneficial use in on-farm irrigation?"

"Beneficial use" includes (Burt, 1990):

1. ETAW. Applied irrigation water used for evapotranspiration (ET).
2. LR. Leaching Requirement. The fraction of applied water necessary for adequate leaching to maintain a desired soil salinity. The LR concept does not account for non-uniformity of irrigation.
3. Water for special cultural practices (eg., weed germination, climate control).

"Reasonable use" recognizes that an irrigation efficiency (with no under-irrigation) will always be less than 100%. Irrigation Efficiency (IE) is defined as:

$$IE = \frac{\text{Irrigation Water Beneficially Used}}{\text{Irrigation Water Applied}} \times 100$$

It is impossible to apply irrigation water with 100% irrigation efficiency without reducing crop yields. All irrigation systems have inherent non-uniformity of water application across a field; "good" Distribution Uniformities (DU) in most of California are accepted to be 75 - 80%.

$$DU = \frac{\text{Minimum infiltrated in a field}}{\text{Average infiltrated in a field}} \times 100$$

With no under-irrigation in a field, and neglecting Leaching Requirement (LR), a DU of 80% means that about 20% of the infiltrated water is destined to deep percolation below the root zone (ie, drainage water). Many Imperial Valley soils have unique sealing characteristics (Robinson, 1980; Grismer, 1986) which, combined with the predominate surface irrigation methods within IID, may enable IID farmers to have higher DU's (eg., about 90%) than farmers in other areas of California.

"Reasonable use" of water recognizes the need for "beneficially used" water, plus the extra water used in non-uniformity, evaporation, inevitable poor timing, and (sometimes) tailwater runoff. What constitutes "reasonable use" varies with time and location, and must account for economic, social, agronomic, human, and other factors. What is reasonable today may be considered unreasonable in 20 years in the future.

Tailwater runoff has been and continues to be an important item in efficiency discussions in IID. However, this report does provide answers to the tailwater questions.

A list of questions must be addressed in defining the future IID water needs in the "reasonable and beneficial use" categories. The major sub-categories are:

1. Beneficial Use.
   a. ETAW. Crop Evapotranspiration. Studies of IID water use have often targeted estimated ET for a single year and used those values in projecting future needs. Future needs have considerable uncertainties. Even present ET requirements of specific crops are uncertain. Researchers commonly acknowledge that the ET estimation techniques are only accurate within plus or minus 10% without extensive field verification.

      Even if the present ET requirements were known precisely, there are factors which may cause the ET to increase in future years. Those factors include:

      1. Reduced salinity stress due to better salt management.
      2. Elimination of poor yield spots on fields.
      3. Reduction of scald on alfalfa.
      4. Reduction of other disease problems.
      5. Improvement of irrigation DU.
         - Reduced root pruning.
         - Minimizing under-irrigation at some points in the field.
      6. Improved soil fertility.
      7. Crop mix change.
      8. Global warming, resulting in higher temperatures.
      9. Tighter drain spacing, contributing to a healthier root zone.
      10. Controlled traffic farming to reduce machinery compaction (eg., row alfalfa instead of border strip).
      11. More frequent irrigations.

b. LR. Leaching Requirement. The following items have been identified as possible reasons to increase estimates of how much deep percolation is needed:

1. Preferential flow of water during infiltration into soils. Some of the water which deep percolates moves through large cracks and is not effective for leaching.
2. High temperature adjustment of salt tolerance values.
3. Increasing salinity of Colorado River water in future years.
4. Consideration of DU. Many discussions of IID salinity problems have neglected the importance of DU, and assume that all points in the field receive the same amount of water.
5. Consideration of LR in light of crop rotations on fields. The LR should be based upon the most salt sensitive crop grown in a field during a rotation, rather than the crop presently planted on that field.
6. Development of new techniques to facilitate more leaching. On many soils in IID, with the present farming and irrigation practices, large amounts of leaching water will damage the crops (due to poor aeration and drowning). New practices such as drip irrigation, sprinkler irrigation, row alfalfa, tighter drain spacing, and mole drains, may enhance the ability of farmers to adequately leach salts from the soil.

2. Reasonable Use.

a. Deep percolation due to non-uniformity. As IID farmers develop new farming/irrigation techniques, they may be able to eliminate under-irrigation. This will result in more deep percolation due to non-uniformity, as illustrated in the figure below.

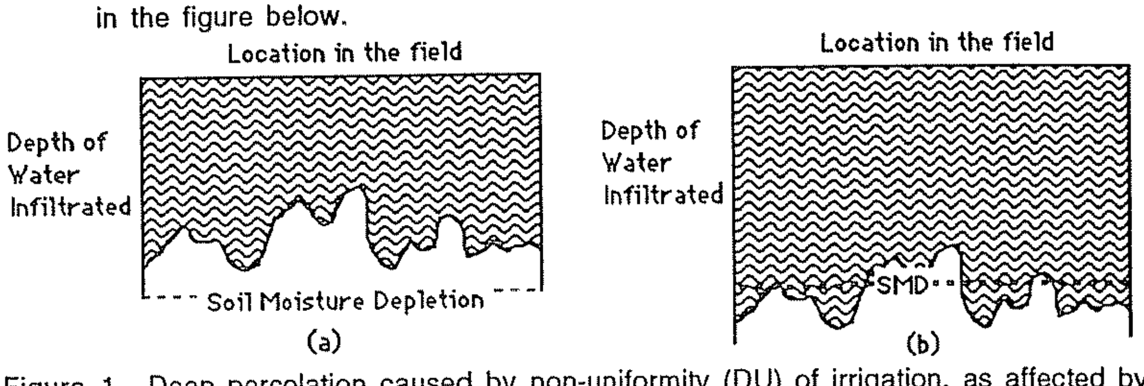

Figure 1. Deep percolation caused by non-uniformity (DU) of irrigation, as affected by under-irrigation. Both (a) and (b) have non-uniformity. However, since (a) is completely under-irrigated, the DU does not contribute to deep percolation. As the under-irrigation is reduced (b), deep percolation due to non-uniformity appears.

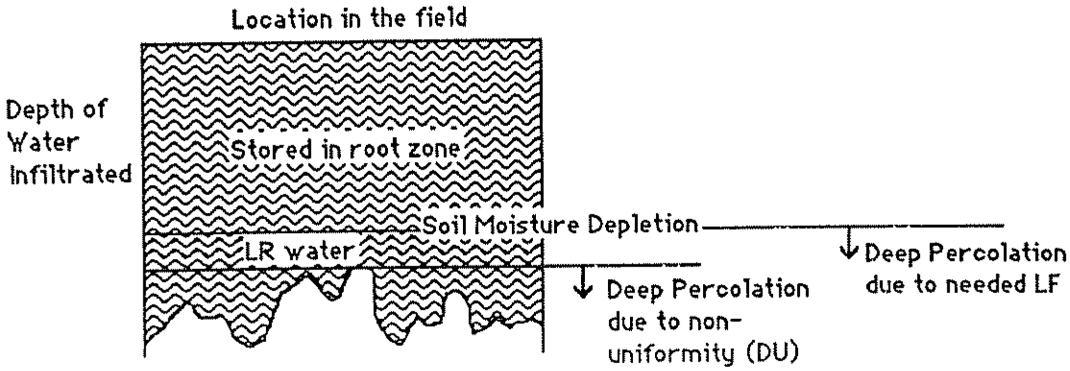

Figure 2. Deep percolation due to LR, LF, and DU. This is a case of "perfect timing" of irrigation, in which enough water has infiltrated at the "driest" point in the field to prevent salt build-up there. LF (Leaching Fraction) accounts for all actual deep percolation, not just the LR.

b. Tailwater runoff. Some tailwater runoff is considered reasonable at present because of:

1. Unknowns regarding disease transmission through recycled tailwater
2. High costs associated with installation of tailwater return systems.
3. Questions regarding proper management of water and labor with tailwater return systems.
4. Questions regarding the importance of tailwater runoff to removing salt which has been deposited on the soil surface through evaporation.
5. Unknowns regarding the need to dilute tile drain water before it goes into the Salton Sea.

Future costs and answers to unknowns will determine the "reasonableness" of tailwater runoff in 10-20 years.

Salinity - General

The primary salinity effects on soils and crops are:

1. Leaf burn (due to high irrigation water salinity, EC_W, sprinkled on leaves).
2. Poor germination or emergence of seedlings (due to high soil salinity, EC_e, in the seedbed).
3. Stunted or reduced yields caused by high root zone salinity, EC_e, after germination/emergence). [*LR deals only with this aspect*].
4. Stunted or reduced yields due to specific ion root toxicity (eg., boron, lithium).
5. Soil structure/aeration/water infiltration problems due to a high percentage of sodium in the soil.

For each problem, researchers have tried to develop:

1. Quantitative relationships between the degree of problem and crop yields.
2. Methods of predicting the degree of the problem (eg., average root zone EC_e) based upon irrigation water quality and various irrigation management schemes.

The almost infinite combinations of crops, varieties of crop, temperatures, soils, irrigation water qualities, irrigation practices, and other cultural practices have frustrated attempts to define (1) and (2).

The amount of extra water which is needed as deep percolation for adequate salt leaching in Imperial Valley is not precisely known, and there have been vastly different estimates regarding the need. Differences occur partly because good salinity research in the U.S. did not begin until the 1950's, and much of that work has been done under conditions different from those in Imperial Valley. Special Imperial Valley conditions include:

1. High temperatures.
2. Cracking clay soils, in which much of the irrigation infiltration into the soil is lateral (from the cracks) rather than vertical (from the soil surface).
3. High concentrations of calcium in the irrigation water.
4. Very low infiltration rates.
5. Artificial drainage (eg., tile drains).
6. Significant preferential flow of water during infiltration.
7. Possible significant contribution of tailwater runoff to maintaining a desirable salt balance.

Root Zone Salinity and Crop Yield

Plants can withstand soil salinity up to some "threshold" level without any decrease in yield. Yields decline linearly as the soil salinity increases beyond the threshold level.

Published crop salt tolerance threshold values are fairly consistent throughout U.S. literature. A major question remains regarding the proper use those values to predict the needed Leaching Requirement (LR). EC_e values (saturated paste extract salinity, in dS/m) for some crops are given in Table 1.

Table 1. Salt tolerances (conventional) for selected crops (Rhoades and Loveday 1990).

Crop	Threshold ECe	% Yield Decline/(dS/m)
Alfalfa	2.0	7.3
Lettuce	1.3	13
Onion	1.2	16
Sudangrass	2.8	4.3
Tomato	2.5	9.9
Wheat (semi-dwarf)	8.6	3.0

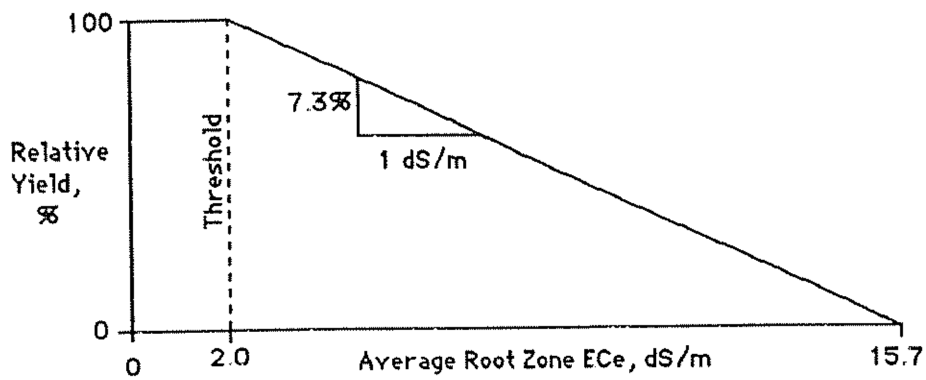

Figure 3. Yield versus soil salinity for alfalfa.

Most threshold EC_e values were developed with research using an artificially salinized soil, with a high leaching fraction to produce a uniform soil salinity with depth. The air/water temperatures in the salinity research were generally lower than summer temperatures in IID. Results of salinity research are affected by irrigation frequency; very frequent irrigations will keep soil salts more dilute than will infrequent irrigations.

In the field, salt concentrations will theoretically tend to increase at the bottom of the root zone due to downward leaching of salts during irrigation. The salinity in the upper portion of the root zone will theoretically be influenced mostly by irrigation water quality; the lower root zone salinity will be influenced more by the size of the LR. There may also be a high salinity at the soil surface in some conditions. Unfortunately for planners in IID, this theoretical salt distribution does not appear to apply to cracking soils as well as to typical sandy, loam, and silt loam soils.

A variety of researchers have tried to predict crop response to root zone salinity distribution. They are summarized in Table 2.

Table 2. Research regarding root zone salinity and yield.

Researcher	Conclusion regarding yield response
Bower et al. (1969)	Average root zone salinity, regardless of the salinity profile shape (crop - alfalfa)
van Schilfgaarde et al. (1974)	As long as roots have access to water of low salinity they are able to utilize some water of high salinity without adverse effects.
Ingvalson et al. (1976)	Average profile root zone salinity (alfalfa)
Rhoades (1983)	Linear average of root zone salinity (conventional irrigation management)
	Weighted salinity for water uptake location (high frequency irrigation management)

The conclusions by Rhoades (1983) appear to have the greatest agreement with actual field studies.

Leaching Requirement (LR)

Definition of LR.

The Leaching Requirement (LR) is the fraction of infiltrated water which must pass through the root zone (and become deep percolation) to maintain some desirable root zone salinity level.

LR values may vary from .01 to .40, depending upon the crop, irrigation water quality, irrigation frequency, soil type, and climate. As will be explained below, the calculation of the LR value is not an exact science. The "LR" value is used in computations to determine the amount of water which must infiltrate at a point:

$$\text{Infiltration needed} = \frac{\text{Soil Moisture Depletion}}{1 - LR}$$

Definition of LF

The Leaching Fraction (LF) is the portion of the infiltrated water which actually deep percolates below the root zone. In general, only a portion of the LF can be considered beneficial. Many, if not most, discussions of leaching assume that irrigation is uniform (ie, DU = 100%), and therefore the assumption is that LF = LR. Actually, the LR is the fraction of infiltrated water which must infiltrate at the point in the field which receives the least amount of water (see Figure 1). In order to determine the water requirement for a whole field, the LF must include water necessary for LR, plus water for non-uniformity (Burt, 1990; Stegman et al., 1981). The minimum LF required on a field to avoid under-irrigation (due to non-uniformity of water application) is:

$$LF = 1 - \left[\frac{DU}{100} \times (1-LR)\right]$$

where DU = Distribution Uniformity of field irrigation, %

The gross irrigation water needed (neglecting evaporation and tailwater runoff) is:

$$\text{Gross needed} = \frac{\text{Net required}}{1 - LF}$$

For questions of required irrigation water, LF should be considered rather than LR.

Conventional Equations for LR.

Since the 1950's, there have been a variety of formulas used to predict the necessary LR. The "conventional" solutions share the following assumptions:

1. There is no chemical precipitation in the root zone.
2. There is no salt contribution from fertilizers.
3. There is no salt contribution from soil weathering.
4. There is no water uptake from a high water table.
5. The soil wets in a classic fashion during an irrigation; that is, a distinct wetting front moves down from the soil surface.

In the Imperial Valley, there can be crop water uptake from a high water table, and the cracking clay soils do not have a classic wetting front during an irrigation. There is also a question about chemical precipitation. Therefore, the classical LR formulas (in Table 3) may not apply in some of the soils within IID.

Table 3. Classical LR formulas from the literature.

Formula (LR =)	Important values	Source
EC_w/EC_{dw}	EC_{dw} = (EC_e at 50% yield reduction) (uniform salinity profile, UP)	Bernstein (1964)
	25% of LR predicted by Bernstein (1964) for low-mod salt tolerance, UP	Bernstein & Francois (1973)
	40% of LR predicted by Bernstein (1964) for salt tolerant crops, UP	Bernstein & Francois (1973)
	EC_{dw} = 2 x (EC_e at 100% yield reduction) (non-uniform profile , NUP)	van Schilfgaarde et al (1974)
	$EC_{dw} = 5\ EC_e - EC_w$ where EC_e is value at 0 % yield decline NUP; logic based on average soil water salinity	Rhoades (1974)
	EC_{dw} = EC_e at 100% yield decline, UP	Ayers (1977)
	EC_{dw} = EC_e of a uniformily salinized root zone w/ 50% crop yield reduction	Bouwer and Idelovitch (1987)
Other	LR depends upon ECw and irrig. frequency	Rhoades and Loveday (1990)
	LR depends upon ECw & linearly-averaged, mean root zone salinity. Shown in the Fig. 4	Hoffman (1985)

Rhoades and Loveday (1990):

ECe(threshold)/ECw	Leaching Req (LR) High Freq.	Leaching Req (LR) Low Freq
1.0	.23	.32
1.25	.13	.22
1.5	.08	.17
1.75	.05	.12
2.0	.03	.10

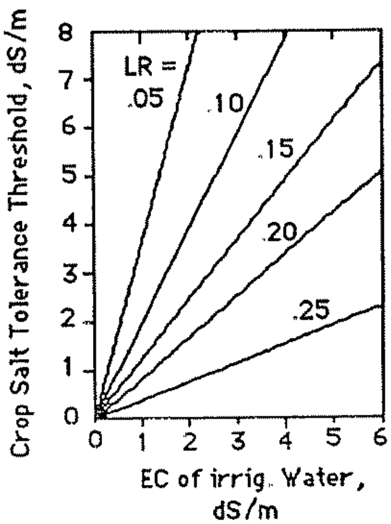

Figure 4. Solution for predicting LR based upon EC_W (Hoffman, 1985)

Hoffman (1985) examined field data from several locations, including Imperial Valley (Lonkerd et al, 1979). He then compared the "experimental measured leaching requirement" in those trials which was necessary for no yield reduction, versus the predicted results using various equations. His comparison is shown in the following figure.

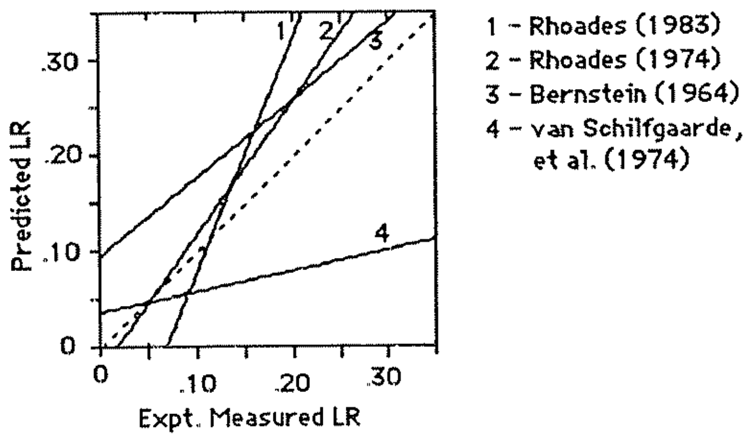

Figure 5. Comparison of LR equations by Hoffman (1985)

The obvious conclusion is that none of the equations precisely predict the limited field results. Furthermore, since each field experiment will provide somewhat different results, it is difficult to know which equation is closest to the "truth". It appears that the equation by Rhoades (1974) most closely matches the field conditions, and may be the most applicable to IID conditions.

Salt Precipitation and LF - Chemical modeling

Much of the work on salt tolerance of crops and LR has been done with chloride salts, which were fairly soluble. The question regarding precipitation arises with high concentrations of calcium in the irrigation water, and the possible formation of lime ($CaCO_3$) or gypsum ($CaSO_4$).

Since the mid 1970's, some researchers have questioned the assumptions that (1) salt precipitation in the soil, and (2) that soil weathering contributions to salinity, are negligible. These assumptions are of primary importance to irrigation management, and to estimates of "conservable water", in the Imperial Valley.

Bliesner, et al. (1977) used irrigation water with EC's ranging from 1.0 - 2.8 in the Ashley Valley in Utah. The water had high levels of calcium salts. Even with no leaching, there was almost no increase in soil salinity during their experiments. Ingvalson, et al. (1976) referred to earlier work which (1) had defined "effective salinity" as salinity in excess of the $Ca(HCO_3)_2$ and $CaSO_4$ in the water, and (2) had considered "effective" soil salinity as only consisting of concentrations of (Cl + 0.5 x SO_4). Oster and Tanji (1985) concluded that the amount of precipitation depends upon the Leaching Fraction (LF) and that with a small (LF), up to half of the salts found in Colorado River water would precipitate out in the soil. [*note: this forms the basis for the Bower (1988?) comments, Exhibit 18*]. The conclusions of Oster and Tanji are based upon chemical models in computer programs. Figure 6 shows their results.

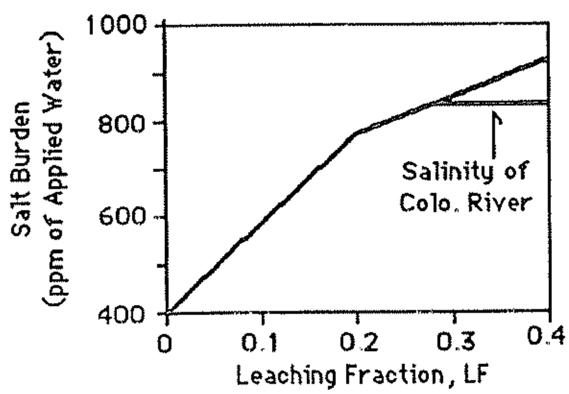

Figure 6. Salt burden of drain water as a function of LR (Oster and Tanji, 1985).

Table 4. Max. EC_e values theoretically possible in IID soils, based upon modeling work of Oster and Tanji (1985), as shown in Figure 6.

LF	Salt Burden[1)]	Ratio SB/830[2)]	ECdw/ECw Ratio/LF[3)]	**(ECe at bottom of root zone)** ECe/ECw (assumes ECe = .5ECdw)
.05	510	.61	12.3	**6.1**
.10	590	.71	7.1	**3.6**
.20	780	.94	4.7	**2.3**

Notes:

1) The Salt Burden is determined from Figure 6, assuming Colorado River water for irrigation. The value depends upon the leaching fraction, LF.
2) The Ratio is the theoretical ratio of deep percolated salt compared to infiltrated salt. A ratio of 0.61 indicates that only 61% of the salt will deep percolate; 39% of the salt coming in with the irrigation water will precipitate out in the root zone.
3) The (Ratio/LF) is the theoretical relative concentration factor of the drainage water EC, as compared to the irrigation water EC. A value of 12.3 indicates that the drainage water would have 12.3 times greater EC than the irrigation water

Rhoades (1986) also concluded that there is significant salt precipitation in soils irrigated with Colorado River water. Furthermore, he states that "...for an irrigation water of 1 dS/m electrical conductivity, leaching fractions of .022 to .067 would be needed for the most salt-tolerant and sensitive crops, respectively."

Salt Precipitation and LF - Field Work in IID Compared to Theory

Some field studies in Imperial Valley support the idea that salt precipitation may occur between the soil surface and the tile drains. Kaddah and Rhoades (1976) and Grismer (1990) showed that flows into the Salton Sea have a lower percentage of calcium than do flows into IID. Kaddah and Rhoades (1976) concluded, however, "... that the effluent salinity reflects the ground water salinity more than the root zone salinity." Furthermore, they stated that "...salt balance as now evaluated is not a generally meaningful criterion on which to base the adequacy of leaching and salinity control of large irrigation projects."

There is strong field evidence in the Imperial Valley that the theoretical models (eg., Oster and Tanji, 1985) do not adequately explain the salt balance within the root zone in IID. As an example, Table 5, showing soil salinity from the Tailwater Recovery Demonstration fields (IID, 1990) can be examined.

Table 5. Maximum EC_e values from 24" or deeper in the soil (max. depth = 60"). Values taken from four Tailwater Recovery Demonstration fields in IID (IID, 1990).

	Close to drain			Midway between drains			
Field #	1985	1988	1990	1985	1988	1990	
1 North	9.1	5.0	6.4	8.7	3.9	4.8	
1 South	7.6	5.6	5.4	8.1	5.0	5.1	
2 North	16.1	10.7	11.1	15.2	8.8	9.6	
2 South	13.9	14.1	16.7	13.0	13.5	15.5	
3 North	9.3	10.1	10.6	8.4	9.2	9.0	
3 South	7.8	7.9	10.0	7.7	8.3	10.0	
4 East	3.9	3.8	2.3	5.3	3.4	2.6	
4 West	2.0	1.3	1.7	6.4	2.4	4.0	
averages:	8.7	7.3	8.0	9.1	6.8	7.6	(7.9 ave)

The data from Table 5 is useful in examining the applicability of the theory proposed by Oster and Tanji (1985), and arguments submitted by Rhoades (1986). Their argument is that the salinity in the soil root zone will not get dangerously high (for plants) because as the salinity increases, the salts will precipitate out, thereby preventing the soil salinity from rising to a very high level. As mentioned earlier, Rhoades (1986) proposes LF's of .022 - .067 for the most salt tolerant and sensitive crops, respectively.

The Tailwater Demonstration study shows an average maximum soil salinity of 7.9 dS/m in 4 fields. Other studies (Lehman et al, 1968; Hagemann and Ehlig, 1980, van der Tak and Grismer, 1987) have shown numbers in this range in production fields within IID. If these field were typical of IID fields, the LF is 0.15 (representing 15% of the infiltrated water, which is about 10% of the Drop 1 discharges). The work of Oster and Tanji (1985) predicts that with a LF of 0.15, the maximum ECe would be about 2.8 dS/m, rather than the 7.9 dS/m measured.

The "basic" LF formula of

$$LF = ECw/ECdw$$

assumes no precipitation of salts, and was not developed for cracking clay soil conditions. Using that equation with an ECw of 1.2 dS/m, and an average LF of 0.15, the maximum ECe can be estimated as follows:

$$\begin{aligned} ECdw &= 1.2/.15 \\ &= 8.0 \text{ dS/m} \end{aligned}$$

Assuming that the maximum ECe = 0.5 x ECdw

max. ECe = 4.0 dS/m

This value of 4.0 dS/m is higher than the 2.8 dS/m predicted by Tanji and Oster's procedures, but it still does not match the average (of maximum ECe's) of 7.9 dS/m shown in Table 5.

Possible conclusions could be:

1. The actual LR needed is about twice that which is predicted by the "classical" LR methods. This could be explained by the fact that much of the drainage water never passes through the root zone soil, but enters cracks and passes immediately down to the soil below the root zone.

and/or

2. The average LF in the 4 tailwater fields was considerably less than 0.15.

The weak link in the discussion above is the lack of large amounts of field data on soil salinity. Extensive soil salinity data needs to be collected through many fields in order to lay this issue to rest. The thoroughness of data collection within each single field must include ample horizontal and vertical sampling to account for both (a) non-uniformity of water infiltration throughout the field (due to different opportunity times) and (b) the apparent horizontal movement of water from the cracks into the soil.

If insufficient data is collected, there is the tendency to assume that the values are "typical", even though that may not be the case at all. To better understand salinity and leaching in a field, it is important to know what the "extreme" values are, not just the "average" or "typical" EC values. If the "average salinity" in a field is "just right", then half of the field will have excessively high salinity, with resulting yield decreases.

Initial conclusions regarding LR and LF

1. Equations to predict the proper LR vary, are inconsistent, and were not developed to match the IID conditions.
2. Estimates of salt precipitation within the crop root zone appear to be high.
3. **More soil root zone ECe data must be collected, along with measurements of LF, to better evaluate the LR prediction equations. .
4. It is essential to deal with LF (which includes non-uniformity) rather than LR.

High Temperature/Salinity Relationships

General

Insufficient research to determine "threshold ECe" values for crops has been conducted under the extremely hot conditions which are typical of Imperial Valley summers. Discussions of LR within IID have used salt tolerance values obtained in more moderate climates. Crops in the Imperial Valley will suffer salt stress/damage at lower soil salinities than in other areas because of the high temperatures, so current calculations of LR should be modified accordingly. Unfortunately, no one knows precisely how to adjust of salt tolerance data for high temperatures.

Research Results

Several workers have noted the general relationship between high temperatures and increased salinity stress. Braun and Khan (1976) noted with lettuce seed germination that "high temperature and salinity appear to accentuate each other's effects. Thus, salinity, low osmotic potential, water deficit, and other soil related stresses may not be readily evident at low temperatures but may find expression at high temperatures." Elsheikh and Wood (1989) noted a definite correlation between high temperature and salinity damage to chickpea and soybean crops. Hampson and Simpson (1989a, b) studied early growth of wheat and determined that temperature stress on wheat germination showed no effect in the absence of salinity. However, high salinity levels showed a large effect when temperatures were high. There was also a definite interaction with salinity and high temperatures during early seedling growth. Guggenheim and Waisel (1977) noted that Rhodes grass yields dramatically dropped with high temperatures, but it was not clear how to separate the salinity and temperature effects.

Maas and Hoffman (1977) noted that "many crops seem less salt-tolerant when grown under hot dry conditions than under cool humid ones". They quoted earlier research which noted salt-temperature interactions with alfalfa, bean, beet, carrot, cotton, onion, squash, tomato, clover, and salt grass crops.

There is little quantitative, transferrable information in the research. Francois and Goodin (1972) studied sugar beet germination and stated that "when the temperature exceeds 25 C, an approximate 3 dS/m decrease in salinity must accompany each 5 C increase in temperature to prevent reduction in germination damage." They also noted that sugar beets germinated at 25-35 C had about half the germination rate as at 10-15 C, with about 3 dS/m salinity. At 10-15 C, there was almost no effect on germination due to increased salinity. In the Imperial Valley, soil temperatures are in the 40 C range during sugar beet planting time.

Summary of Temperature/Salinity Interactions Research

1. It is well established that crop sensitivity to salinity increases as temperatures increase.
2. It is not clear how to properly adjust the "threshold ECe" values for salinity sensitivity of crops, to compensate for high temperatures.

Yield, ET,and Salt Sensitivity of Alfalfa

General

Alfalfa is a major crop within IID. Factors which affect the ET rate of alfalfa have an important impact upon IID water requirements. Therefore, this section will review some pertinent information regarding alfalfa and water within IID.

General Yield/ET Functions of Alfalfa

Most researchers have determined that alfalfa yield increases linearly as ET increases. Some of the yield functions which have been developed are shown in Table 6.

Table 6. Yield Functions for Alfalfa

Yield = -3.73 + .12 ET	(Yield = tons/ha; ET = cm)	(Donavan and Meek, 1983)
WUE = 1.73 - .041 ET	(Water Use Eff = tons/acre-6 inches of water; ET = inches of water)	(Guitjens, 1982)
WUE = 18.25 kg/ha-mm		(Bolger and Matches, 1990)
Y = - 833 + 159 ET	(Y = kg/ha x 1000; ET = cm/yr)	(Heichel, 1983)
20% under-irrigation of alfalfa = 30% yield decline *Note - this was from a field study in Imperial Valley, and may indicate the relationship between salinity effects and soil dryness		(Oster, et al., 1986)

These yield functions are important because it is generally understood that if yields decline due to salinity, the ET also declines (Hanks, et al., 1977). The same relationship occurs if yields decline due to scald or drainage problems.

Most studies of alfalfa yield have assumed that since it is a vegetative crop, there are no critical growth stages. However, Halim et al (1989) note that stress at bud or flower stages results in disproportionate deterioration of total herbage forage quality. Other researchers have noticed that alfalfa is very sensitive to both dryness and excess water immediately after cutting (Sheaffer et al, 1988). That poses a problem for IID growers with flood irrigation because it is difficult to irrigate without also saturating the soil. Row alfalfa may alleviate part of the saturation problem.

Waterlogging/Scald of Alfalfa

Alfalfa is notorious for its susceptibility to excess soil water (Heichel, 1983). Lehman, et al. (1968) noted that in Imperial Valley, 36 hours of saturation can kill alfalfa. Meek, et al. (1986) observed that top growth of alfalfa can be reduced by 50% when plants are flooded for 2 days at 32 C. Root damage in the same research was only 1% in a clay loam soil compared to 10% in a silty clay soil. Barta (1988), working with mild temperatures, noted that non-clipped alfalfa plants could withstand flooding of up to 14 days without damage.

As with salinity tolerances, different cultivars of alfalfa have different sensitivities to waterlogging. The cultivar Salton is considered tolerant to adverse waterlogging during high temperatures (Donovan and Meek, 1983).

The exact physiological cause of alfalfa damage from waterlogging has been debated. Heichel (1983) states that it is due to anoxia (lack of oxygen) and impaired mineral absorption by the roots. Sheaffer et al. (1988) state that damage is due to the lack of oxygen in the root zone and the formation of ethanol and other toxic substances in the roots. They state that the effects of phytophthora root rot are secondary. Meek et al. (1986) felt that oxygen deficiency, not ethylene toxicity, seemed to be the problem when alfalfa was flooded. Barta (1988) found that cultivars highly resistant to phytophthora root rot are generally more resistant to flooding injury.

High Water Table Effects on Alfalfa Yield

Rai et al. (1971) found that alfalfa yields are dramatically affected (decreases of 61%) if the water table rises immediately after harvest. This has important implications for IID irrigation practices.

Salinity Effects on Alfalfa (most research done at "normal" temperatures)

Ingvalson et al. (1976) determined that average profile soil salinity is a useful index of salinity for relating alfalfa yield response under conditions of flood irrigation management. Bower et al. (1969) also found that alfalfa yield was highly related to average root zone salinity, regardless of the salinity profile shape. Bernstein and Francois (1973) believed that alfalfa responded more to calculated mean salinity against which the water was absorbed than to soil water salinity averaged by depth.

Ingvalson et al. (1976) determined the equivalent "threshold EC_e" would be about 1.7 dS/m - 2.4 dS/m, depending upon the moisture level in the soil. They also noted that alfalfa roots may become more sensitive to salinity with age. The most commonly quoted "threshold EC_e" for alfalfa is 2.0 dS/m (Rhoades and Loveday, 1990; Maas and Hoffman, 1977). Hoffman et al. (1975) found a "threshold EC_e" of about 1.7 dS/m in studies with average daytime temperatures of 28 C (considerably lower than IID summer temperatures).

Various alfalfa cultivars have different sensitivities to salinity. Ashraf et al. (1987) indicated that there is a good potential to breed new cultivars of alfalfa for improved salt tolerance.

It has been noted that alfalfa seedlings, as with most crops, can suffer great damage if the seedbed is salty and dry (Assadian and Miyamoto, 1987). Heichel (1983) states that germination is practically inhibited at soil moisture tensions (including matrix and osmotic potentials) of -12 to -15 bars.

Robinson (1980) examined leaf burn problems with sprinkler irrigation of alfalfa in the Imperial Valley. He found that application rates of greater than 5 mm/hr greatly compacted the soil, but that application rates of less than 4.0 mm/hr caused significant leaf burn. Ninety three percent of the plants had leaf burn with an application rate of 1.8 mm/hr, versus 2.5 percent damage at 4.0 mm/hr.

Special Soil Conditions in Imperial Valley

In much of the Imperial Valley, border strip irrigation is actually "irrigation by cracks". The size of the cracks will determine the amount of infiltrated water during an irrigation. van der Tak and Grismer (1987) found that the amount which will infiltrate during a border strip irrigation is almost equivalent to the volume of cracks at that time.

The cracks allow drainage from tile lines to occur almost immediately during/after an irrigation, although the hydraulic conductivity of the soil is not high enough to permit such rapid drainage. This early water drainage is probably not very effective in leaching. van der Tak and Grismer (1987) conclude that "traditional design concepts of....leaching fraction.....have limited meaning in the context of heavily cracking soils due to crack dominance of water flow through the soil... However, depending upon the average crack depth, irrigation water may not adequately....leach, the root zone."

Adequate leaching of alfalfa fields is so difficult on some Imperial Valley soils that farmers must depend on leaching which occurs while growing other crops, in order to establish a long-term soil salinity which is low enough to grow the crops.

Work should be conducted on ways to increase the effectiveness of root zone leaching with a given LF. New methods of leaching will be accompanied by new irrigation methods and new ways to cultivate crops. As an example, it is generally understood that sprinklers provide more effective leaching of salts (per unit of water infiltrated) than surface irrigation on most soils. This is because a greater percentage of the infiltrated water moves down through micro-pores rather than macro-pores; crack infiltration is also minimized. Wide adaptation of sprinklers throughout IID would affect water delivery requirements, air quality, irrigation system costs, tailwater management, and labor requirements.

Conclusions and Estimates For the Future

Research clearly shows that some trends do exist and that many current formulas/values are questionable at best. There seem to be two choices:

1. Do not make a decision because it is unclear what "truth" is, even though it seems obvious that the present numbers are probably incorrect, or
2. Make an estimate and depend upon future research to (a) verify the estimates or (b) develop better estimates.

The estimates/predictions/conclusions are:

1. Conventional "threshold ECe" values for crops in IID should be reduced by 25%, to account for the extremely high temperatures. The new "threshold ECe" value for alfalfa should be 1.5 dS/m rather than 2.0 dS/m.
2. The required LR can best be estimated by the equation:

$$LR = \frac{ECw}{5\ ECe - ECw}$$

where ECw = EC of the irrigation water, dS/m
ECe = Threshold ECe of the most sensitive crop to be grown in a rotation on that field.
It is based upon the average root zone ECe.

This definition has a powerful conclusion which is not currently accepted - that the leaching requirements in IID should not be calculated based upon the crops currently planted, but rather, on the most sensitive crops to be grown on the fields.

This particular equation of LR (from Rhoades, 1974) was not developed for the majority of IID soils. The key assumptions which make it incorrect are:

a. Preferential flow of water through cracks is ignored (ie, it underestimates the LR needed).
b. Salt precipitation in the root zone is ingored (ie, it overestimates the LR needed).

The net result may be that it is approximately correct.

3. LF requirements should assume DU values ranging from 90% - 75% (clay - sand). This is higher than in most areas of California, but corresponds to the unique sealing properties of some Imperial Valley soils and the fact that surface irrigation is used.

4. Evapotranspiration requirements will increase by 5 - 10% as farming practices/drainage/salt control improves. This does not account for increases in temperature, and ignores introduction of new short season varieties of crops.

5. A desirable Leaching Fraction (LF) for a heavy clay soil, averaged over several years and crops, is estimated as follows:

   LR - Based upon a modified threshold ECe of 1.5 for alfalfa. This assumes that alfalfa has a deeper root zone than the more salt-sensitive crops which will be grown in a rotation. If the average ECe in the root zone is 1.5 for alfalfa, it may be 1 - 1.3 for shallower rooted crops in the same soil, since they will not be exposed to the deeper, more saline soil profile.
   - Assumes that Colo. River water salinity will rise to ECw = 1.4 in 10 years.

$$LR = \frac{ECw}{5ECe - ECw} = \frac{1.4}{[5 \times 1.5] - 1.4} = .23$$

   LF - Based upon a DU of 90%

$$LF = 1 - [\frac{DU}{100} x (1 - LR)] = 1 - [.90 \times (1 - .23)] = .31$$

   Many IID farmers might immediately state that such a high LF would kill their plants because of suffocation; they just cannot get that much extra water into the ground for some crops. The responses to this could be:

   a. Perhaps that is true.
   b. Perhaps, when one considers the total crop rotation plan, it may be possible to have a higher LF than presently obtained.
   c. These computations do not state what is currently happening - they point to what may be realistic future needs, when crop mixes may be different and new irrigation/cultivation techniques may enhance leaching abilities.

Recommendations for Future Research

1. More data is needed to correlate LF with soil ECe. This would involve extensive 3-dimensional soil sampling, and probably include ECsw estimates made with surface salinity sensors. New research should be conducted on representative soils within IID, and probably will require a research plot design in which the LF can be carefully measured in each treatment.
2. Better information is needed for the relationship between salt sensitivity and temperatures.
3. Research should better define what constitutes the "root zone depth" for various crops grown in rotation in IID.
4. Development of new high yielding, short season crop varieties and more salt- and waterlog-resistant alfalfa cultivars should be encouraged.
5. Work needs to be done on improving the efficiency of the LF through different cultural or irrigation methods.

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